

Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.

Review and Discussion of Literature Pertinent to Crop Rotations for Erodible Soils

C. R. ENLOW, Chief, Agronomy Division
Soil Conservation Service

For sale by the Superintendent of Documents, Washington, D. C., Price 10 cents

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.



Circular No. 559

June 1939 • Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE



Review and Discussion of Literature Pertinent to Crop Rotations for Erodible Soils

By C. R. ENLOW, *chief, Agronomy Division, Soil Conservation Service*

CONTENTS

	Page		Page
Introduction.....	1	Crop-rotation, etc.—Continued:	
Losses in soil organic matter.....	5	Northeastern States.....	25
Nature of organic matter.....	9	Southeastern States.....	27
Crop sequence.....	13	Rotations on the contour.....	31
Crop-rotation experiments at soil and water conservation experiment stations.....	16	Grass-legume mixtures.....	33
Crop-rotation experiments at State and Federal experiment stations.....	18	Rotations recommended for erodible soils.....	36
Northern Great Plains.....	18	Summary and conclusions.....	41
Corn Belt.....	23	Bibliography of crop rotation.....	42
		Mimeographed publications.....	50

INTRODUCTION

Examination of published literature pertaining to rotation of crops and crop sequence in the United States reveals a dearth of information that might be applied in making recommendations for the continued production of crops on land subject to water and wind erosion. Experimental results have been obtained principally on level or gently sloping land, for uniform land conditions at any station are necessary to obtain comparable crop yields. In general, in publications relating to the experiments, no attempts have been made to distinguish between recommendations for erodible soils and those not subject to erosion. Proper land use, except in a few instances, has not been given consideration.

The present condition of our agricultural lands as a result of erosion is pointed out by the National Resources Board (125).¹ Thirty-five million acres of former cropland have been completely destroyed by erosion, 125 million more are severely eroded, and an additional 100 million acres, although not in a serious condition, are subject to active sheet and gully erosion. These figures are from a Nation-wide survey conducted in 1934.

¹ Italic numbers in parentheses refer to Bibliography, p. 42.

In the United States speculative farming has been the general practice, and all possible effort has been made to continue producing cash crops to the exclusion of grasses, legumes, and other soil-improving crops. Continuous production of cotton in the South, corn in the Ohio and upper Mississippi Valleys, and wheat in the central and northern Great Plains and the Palouse country of Oregon, Washington, and Idaho has resulted in an enormous loss of valuable soil through erosion (fig.1). There are no more new lands to move to when the fields become unproductive, and the speculative farming days are ending. Gradually the speculators are being forced out and farmers who love the land and have a real desire to maintain it for future generations are taking possession. The wave of speculative farming, naturally, was from east to west; and the older agriculture of the Eastern States, as would be expected, apparently has a higher percentage of nonspeculative farmers.

Etheridge (38), in considering Missouri's agricultural problems,



FIGURE 1.—Proper land use is fundamental in erosion control. These steeper slopes and hilltops in the Palouse country in Washington are seeded to a legume-grass mixture to protect the fertile lands in the valley.

points out that a conservative estimate of the present productivity of the farm lands of Missouri, excluding bottom land, is only 60 percent of the productivity of the original soil. Under the older but more thrifty agriculture of Ohio, crop returns are estimated to be only 50 percent of what they might be if the lands were virgin. Etheridge lays this loss in productivity to soil erosion and the loss of fertility caused by crop production. He points out that, although better tillage methods and fertilizers are being used and crop rotations are practiced and although improved varieties of crops have been developed and insect and disease control has improved, crop yields have barely been maintained.

The United States Department of Agriculture and the State experiment stations and extension services have been recommending crop rotation with a greater degree of success each year. So long

as land could be kept in continuous cash crop without material reduction in yield, very little progress could be made in the use of rotated crops. When yields began to decrease, farmers were willing to grow such legumes, cereals, and grasses as could be used for soil improvement without losing a year in the production of a cash crop. The spread of the practice of using crop rotations has been slow and has come from the failure of continuous cropping to be relatively profitable rather than from an appreciation of the need for such practice to maintain soils in a high state of fertility. This is aptly expressed by Von Liebig, according to Hopkins (60, p. 592):

Modern agriculture has, up to this time (1859), no connection with the history of the development of man. That history is the mirror which reflects not only his errors and failures, but also his onward progress. But modern agriculture rejects the idea of ever being in error, and therefore she knows nothing of progress.

Crop rotation is generally defined as a more or less regularly recurrent succession of different crops on the same land. Many advan-



FIGURE 2.—Proper utilization of alfalfa or alfalfa-grass mixture in a crop rotation in Illinois. Bringing pasture crops into the rotation provides excellent pasture and also improves the soil.

tages of rotating crops might be enumerated. The most important are (1) maintaining or increasing crop yields, (2) systematizing farming, (3) saving labor, (4) controlling weeds, insects, and plant diseases, (5) aiding in maintenance of organic matter and nitrogen in the soil, and (6) lessening of soil losses through erosion.

Probably the most widely recommended rotation consists of (1) a tilled crop, (2) a small grain, and (3) a legume or grass crop. These crops are grown in the order named. The tendency has been to lengthen the rotation to include a greater number of years of tilled and small-grain crops until forced by reduced yields to resort to a longer period of legume or grass.

Legume and grass crops are generally recognized as soil-building crops, and their use in a rotation is primarily for soil building (fig. 2).

After a soil has been cropped for a long period to corn, cotton, or wheat, the inclusion of a legume for only 1 year frequently increases the yield of the following cash crop very materially, largely through available soil nitrates. This "boost" is sometimes too much for a following small-grain crop, causing excessive vegetative growth and subsequent lodging. For that reason it is advisable to follow the legume with a row crop, particularly in humid regions. Grass in the rotation does not give as great response, generally, in subsequent crop yields, but, on some soils at least, it apparently excels the legume in that it provides a better balance of plant nutrients and a greater improvement in organic content. When it is considered that our very finest soils were built up under grass, the desirability of grass in the rotation becomes apparent. The New



FIGURE 3.—Good land use in Minnesota. The contour strip cropping follows the regular small-grain, legume, and row-crop rotation. Pasture lands lie between the cropland and the timber (note windmill in pasture at right). A trial of Gradoni terraces (Italian-type hillside terraces) can be seen on the hill at the left.

Jersey Agricultural Experiment Station (86) gives data on land that showed an increase of 1,340 pounds of humus per acre after being in grass sod for only 2 years.

On soils that are very low in organic matter, the incorporation at one time of too much carbonaceous material, such as dry grass, ripe grain, straw, or weeds, frequently depresses the yields of following crops, because the soil bacteria and fungi in decomposing the material draw on the limited supply of soil nitrates and thus decrease the amount available for plant growth. Grass-legume mixtures should be used on such soils. In fact, there are many advantages (5, 145) in using grass-legume mixtures for purposes other than soil improvement. These mixtures tend to prevent the heaving of legumes in heavy soils during the freezing and thawing of winter; and certain legumes can be grazed without danger of bloat to livestock, if suf-

ficient grass is eaten with them. The addition of grass to seedings of legumes also aids materially in the control of erosion. This is particularly true of alfalfa, which seeded alone seems to give very poor erosion control on some soils.

Any appreciable change in the acreage of tilled crops, small grain, and grass and legumes has considerable effect on the agriculture of any locality, State, or region (fig. 3). This is more pronounced in areas that have been producing principally one crop. Where the acreage of erosion-control crops, namely, sod-forming grasses and legumes, is materially increased, some increase of livestock and livestock products is necessary. On many farms these products are needed, for farmers depending almost wholly on a single cash crop frequently go without meat, milk, and eggs, which they should have to provide proper nourishment for their families.

It must be recognized that the days of bonanza farming are over. Millions of acres of abandoned land stand in mute testimony to our speculative cash-crop production of the past. Continuous cash-crop production as a permanent practice is impossible. It cannot be continued indefinitely. Gradual diversification of farming is imperative.

LOSSES IN SOIL ORGANIC MATTER

The recommendations of the State experiment stations concerning the use of grasses and legumes in crop rotations have not been sufficiently strong. A study of the application of the recommended rotations on farm lands reveals that soil erosion and depletion have been going on rapidly, particularly on sloping lands. It seems apparent that rotations on sloping lands must contain more years of grasses and legumes if the organic-matter content of the soil is to be maintained.

A study in Ohio (94) compares the effect of rotations and continuous crop production on the organic-matter content and soil nitrogen. The land on which the study was made was drained and limed; no fertilizer was applied. The tremendous loss in organic matter and soil nitrogen is apparent in the following tabular presentation of the results of the experiment (table 1).

TABLE 1.—*Effect of cropping systems upon soil organic matter and nitrogen. Land limed and drained, but otherwise untreated. (Ohio Experiment Station.)*

Cropping system	Duration of test	Quantity per acre in surface soil	
		Organic matter ¹	Nitrogen
	Years	Pounds	Pounds
Corn, continuous.....	32	12, 156	820
Oats, continuous.....	32	21, 722	1, 300
Wheat, continuous.....	32	21, 826	1, 320
Corn, oats, wheat, clover, timothy, rotation.....	32	26, 515	1, 540
Corn, wheat, clover, rotation.....	29	29, 549	1, 760
Original soil (approximate).....		36, 825	2, 240

¹ Organic carbon $\times 1.724$.

Data from Ohio Agricultural Experiment Station Bull. 402, table 7, p. 20.

It is apparent from this table that a rotation containing a grass or legume is of great value in maintaining organic matter and soil nitrogen. It is unfortunate that an accurate comparison with the original soil is not possible, since such information is valuable when attempting to determine what type of rotations are necessary to maintain or actually to improve organic-matter content.

DeTurk (34), in discussing experimental work in Illinois, states that the organic content of the soil under natural conditions increases to a certain point, usually in the early stages of profile development; then a decline follows until in the most advanced stages of development only fairly low amounts are found. The entire process is closely associated with biological processes. Native vegetal cover has a marked effect on the organic content of soils. In early maturity, grassland cover produces a relatively high peak and forest vegetation a relatively low peak. The reduction in organic content that accompanies subsequent soil development tends to equalize organic-matter content in the two soils, and mature prairie soils contain but little more than mature forest soils.

In reference to an experiment conducted on 25 Illinois soils to determine the possibilities of raising their productivity level, DeTurk writes (34, p. 108):

Although the yields on the poorer soils have been more than doubled, they are at best only 50 to 60 percent as high as on the better soils. They cannot be brought up to the higher production levels because nature has done to these soils what man cannot undo. They no longer have their original holding capacity for the basic elements. They no longer have the supplying power for the inorganic salts required. They no longer have facilities for controlling water relations and consequently are susceptible to the vagaries of the weather.

DeTurk further points out that protective and constructive measures can be used. Liming saturates the base capacity and corrects soil acidity. The quality of organic matter but not the quantity may be partly or fully restored by rotations carrying suitable soil-conserving crops. Through exhaustive cropping, the high production capacity of less mature soils has been brought to a low level in a short time by loss of organic matter or of the ability of the soil to supply essential minerals, or both.

Schafer, Wheeting, and Vandecavey (111) point out that the return of crop residues has delayed soil depletion in the wheat soils of Washington but that an application of straw to the soil temporarily depresses nitrate development and thereby reduces yields. As soil becomes depleted of nitrogen and organic matter, it becomes more and more difficult to incorporate crop residues. Soils that develop nitrates most rapidly are well supplied with nitrogen regardless of the fact that applications of straw depress soil nitrates. Yet the soil nitrogen, which is definitely related to soil organic matter, must be maintained if crop residues are to be effective and crop yields maintained permanently on a high level.

The practice of burning stubble has developed because wheat yields have been reduced by plowing large quantities of stubble into the soil. Schafer recommends the inclusion of a legume crop in the rotation as the most inexpensive method of increasing the nitrogen supply in the soil, and he points out that the legume increases the yield of the subsequent wheat crop in addition to increasing the nitrogen content of the soil.

According to Pubols and Heisig (102), the use of improved methods of farming and the introduction of superior varieties of wheat have been largely responsible for maintaining the average yields of wheat in Washington during a period of decreasing precipitation and rapidly deteriorating soils. The rapid decline of the soil resources suggests that effective soil- and moisture-conservation methods must be adopted in order to maintain yields. They accordingly recommend an increase in the use of legumes in areas of heavy precipitation to prevent soil washing and to restore soil fertility, and advise rough tillage and the use of grasses in long rotations in the areas of light precipitation.

Throckmorton and Duley (121, p. 14) point out that crop yields have decreased materially in Kansas over a long period, and present data showing the decrease in the average yields of corn. The trend is shown in the following tabulation of the average corn yields in Kansas by 10-year periods, 1865-1924.

Period of average yields:	Bushels
1867-74.....	33. 6
1875-84.....	36. 9
1885-94.....	23. 8
1895-1904.....	21. 5
1905-14.....	19. 3
1915-24.....	18. 4

The decline in corn yields in Kansas and the decline in nitrogen and organic matter in the soil are very closely related. A comparison of the losses in nitrogen and organic matter by soils left in native sod with the losses by soils of the same kind on adjacent areas that have been under cultivation reveals that 30 to 35 percent of the organic matter and 25 to 30 percent of the nitrogen have been lost from soils that have been cultivated approximately 30 years. Table 2 shows the losses for several soils.

TABLE 2.—*Nitrogen and organic matter in Kansas soils, showing decrease resulting from cultivation*

County and soil type	Cropping system	Content per acre	
		Nitrogen	Organic matter
		<i>Pounds</i>	<i>Pounds</i>
Riley, Oswego silt loam.....	{ Native meadow.....	4, 980	122, 400
	{ Wheat and corn 30 years.....	3, 700	85, 600
Brown, Marshall silt loam.....	{ Native meadow.....	5, 480	139, 200
	{ Average of 6 cultivated soils (corn, oats, and wheat).....	4, 240	106, 800
Russell, Sedgwick clay loam.....	{ Native buffalo pasture.....	4, 260	98, 400
	{ Wheat 30 years.....	2, 960	64, 400
Allen, Oswego fine sandy loam.....	{ Native meadow.....	3, 760	83, 600
	{ Corn and broom corn.....	2, 440	46, 400
Butler, Sedgwick clay loam.....	{ Native pasture.....	4, 280	106, 400
	{ Corn and forage crops.....	2, 800	66, 800
Greenwood, Osage silty clay loam.....	{ Native meadow.....	4, 600	113, 600
	{ Corn 30 years.....	3, 400	73, 200
Greenwood, Summit silty clay loam.....	{ Catalpa grove.....	5, 200	126, 000
	{ Average of 5 cultivated soils.....	3, 400	76, 400
Reno, Reno loam.....	{ Native pasture.....	3, 400	74, 800
	{ Average of 3 cultivated soils.....	1, 920	36, 400
Average.....	{ Native.....	4, 495	108, 050
	{ Cultivated.....	3, 103	69, 500

Data from Kansas Agricultural Experiment Station Bull. 260, table 1, p. 15.

Albrecht points out that from 1918 to 1932, in a fallow, untreated soil, the organic matter dropped from 44,000 pounds per acre to 38,000 pounds but advanced from 44,000 to 52,000 pounds when 2½ tons of red clover were incorporated annually (1, p. 352). In table 3 he gives gains and losses in soil organic matter under various crops and rotations of crops for a period of 17 years. This information is very pertinent, and gives some idea of what may be expected if erosion losses can be prevented.

TABLE 3.—*Gains and losses in soil organic matter (in pounds per acre of surface soil) during 17 years on areas under different systems of cropping and management*

Crop and management	Gain	Loss
	Pounds	Pounds
Rotation—corn, wheat, clover—all crops removed	-----	800
Rotation—corn, wheat, clover—manure equivalent returned	3, 200	-----
Rye and cowpeas—turned under as green manure	1, 200	-----
Rye turned under—summer fallow	-----	14, 400
Red clover continuously—all crops removed	3, 600	-----
Red clover continuously—all crops turned under	9, 600	-----
Alfalfa continuously—all crops removed	10, 400	-----
Grass sod, clipped—nothing removed	10, 000	-----

Data from Soils and Men (U. S. Dept. Agr. Yearbook 1938), table 2, p. 360.

Data from the Ohio experiment station presented in table 4 give the results of a long-time experiment dealing with organic matter in soils, average yields of crops, and the return per acre. The importance of organic matter and soil nitrogen to profitable crop production is definitely established.

TABLE 4.—*Effect of crop rotation upon organic matter, nitrogen content, and crop productivity of the soil¹ at Ohio Agricultural Experiment Station, Wooster, Ohio, for the 5-year period 1921-25*

Cropping system	Amount of organic matter ² per acre in surface soil, 1925	Amount of nitrogen per acre in surface soil, 1925	Average yield of unfertilized crops					Average acre value of crops ³
			Corn	Oats	Wheat	Clover	Timothy	
	Pounds	Pounds	Bushels	Bushels	Bushels	Pounds	Pounds	Dollars
Continuous corn	10, 500	840	6. 7	-----	-----	-----	-----	4. 69
Continuous oats	22, 300	1, 365	-----	15. 3	-----	-----	-----	6. 12
Continuous wheat	22, 100	1, 315	-----	-----	7. 4	-----	-----	11. 10
Corn, oats, wheat, clover, timothy	26, 700	1, 548	26. 3	34. 4	16. 3	2, 030	2, 394	18. 49
Corn, wheat, clover	29, 980	1, 780	40. 0	-----	17. 9	2, 816	-----	25. 86

¹ Soil analysis at the beginning of experiment. Continuous cropping experiment started in 1894, and the 3-year rotation in 1897. Soil organic matter at beginning of experiment was approximately 35,100 pounds per acre and nitrogen 2.176.

² Organic carbon $\times 1.724$.

³ Values used: Corn 70 cents a bushel, oats 40 cents a bushel, wheat \$1.50 a bushel, hay \$15 a ton.

Analytical data from Factors Affecting the Accumulation and Loss of Nitrogen and Organic Carbon in Cropped Soils, Amer. Soc. Agron. Jour. 25, p. 623. Data on crop yields are unpublished results of experiments at the Ohio Agricultural Experiment Station.

Pieters and McKee (99, pp. 431-444), in discussing the use of cover and green-manure crops, point out that improvement in soil organic content is a slow process and that incorporating a single green-manure crop cannot be expected to add materially to the total. Green manuring helps to maintain the total quantity of organic matter; it does not actually increase it. Pieters (98) states that perma-

nent sod is necessary for real soil building and he brings out the fact that new roots are produced every year by a healthy grass sod. The decay of the old roots adds to the organic matter, most of which is retained because the soil is not cultivated.

NATURE OF ORGANIC MATTER

Bradfield (14, p. 88) brings out clearly the changes that have taken place in forest soils under continuous cultivation since the annual supply of leaf litter was cut off by removal of the forests. He states:

As a result of the destruction of these organic residues, biological activities have been reduced, the natural structural aggregates have been destroyed, and the soil particles tend gradually to assume a position of closer packing. In



FIGURE 4.—Many of our native grasses offer real possibilities in the crop rotation not only as cash crops but also for rebuilding soil structure and improving organic matter. This field in Washington has been seeded to a superior ecological strain of Canada wild-rye (*Elymus canadensis* L.) for seed production.

many cases from 25 to 30% more soil is crammed into a cubic foot than was present in the virgin soil. This has reduced porosity, especially the volume of larger pores through which water penetrated readily and through which the soil received the necessary ventilation. As a result of these changes in structure, root development is hampered, the storage capacity of the soil for water is reduced, flood hazard is increased, and the damage from frequent periodic droughts is magnified.

Bradfield also points out that the granular structure of the prairie soils, which is essential for maximum yields, has been practically destroyed in a very short time. He recommends that nature's method of developing good structure be studied (fig. 4).

He shows that grassland farming combined with arable agriculture is the most practicable means of maintaining a desirable soil structure, as evidenced by the experiences of the old agriculture of Europe and

our better farmers and by results from our older experiment stations. He pictures it as a compromise with nature, whereby after we till the soil for a few years in order to produce crops, we turn the soil back to nature in order that she may recondition it. If we follow such practices, Bradfield feels that we can produce as much food and feed from one-half the acreage of intertilled crops as we are now growing, without increasing, and perhaps even decreasing, the cost per unit, and that we can at the same time protect and actually improve our soils for future generations.

He states (14, p. 92):

This solution of the problem seems very old fashioned and trite; and perhaps disappointing to those of you who were expecting something new and novel. But it has this virtue, it is a system which has been used extensively throughout the world ever since the time of the Romans, and where it has been intelligently executed it has worked. It has solved the problem of maintaining soils in as good a physical condition as the material and environment at hand would permit.

Kramer and Weaver (67) give in table 5 data relative to the quantity of living plant material produced underground by various plants.

TABLE 5.—*Actual and comparative dry weights of living underground plant parts in the surface 4 inches of soil*

Plant	Weight per acre	Compared with weight of native grasses ¹		Plant	Weight per acre	Compared with weight of native grasses ¹	
		Low-land	Up-land			Low-land	Up-land
	<i>Pounds</i>	<i>Percent</i>	<i>Percent</i>		<i>Pounds</i>	<i>Percent</i>	<i>Percent</i>
Wheat on lowland.....	1, 338	16		Potatoes.....	321		5
Wheat on upland.....	767		12	Sweetpotatoes.....	214		3
Oats.....	874	11		Peas.....	250		4
Alfalfa, young.....	2, 088		32	Tomatoes.....	232		4
Alfalfa, old.....	3, 497	43		Rough pigweed.....	1, 142	14	
Sorgo.....	1, 320		20	Field bindweed.....	410		6
Maize.....	1, 160	14		Buck brush.....	12, 134	148	
Sudan grass.....	1, 374	17		Bluegrass.....	4, 800	59	
Sweet clover.....	1, 176		18	Slough grass.....	13, 240	161	
Rape.....	785		12	Big bluestem.....	8, 200	100	
Brome grass.....	3, 926	48		Little bluestem.....	6, 600		100
Rye.....	660	8					

¹ The average dry weight of big bluestem is considered 100 percent for crops growing on lowlands formerly occupied by this species. . . . Average dry weight of little bluestem is the basis for calculating percentage yield of underground parts on uplands.

Table in Nebraska University, Conservation Department, Bull. 12, p.87, slightly modified.

A study of this table shows the outstanding value of the perennial grasses in producing quantity of organic material, as compared with annual grasses, cereals, and other crop plants. Cultivation of the soil brings about rapid decomposition of organic materials. The value of perennial grasses is twofold; not only do they produce large quantities of organic matter, but they also preserve it by reducing the number of times the soil is cultivated in a definite period (fig. 5). The advantages of grass in relation to the soil structure are pointed out by Bradfield (14).

Dittmer (35) has found Kentucky bluegrass far superior to either oats or winter rye for soil binding, judging from the number, volume, and total length of roots and root hairs produced.

Smith and others (113) point out the differences in organic matter and the importance of supplying the right kinds and amounts.

They state that organic matter helps to maintain favorable physical conditions in the soil and indirectly helps to make plant food available for crops by furnishing food for the microscopic organisms that effect the various chemical transformations in the soil, whereby the plant food becomes available.

They report that a recent study of results from experiments in many different parts of Illinois shows manure with ground limestone to be the soil treatment that generally gives the greatest profit. This indicates the value of stable manure and suggests the importance of its careful conservation. Sufficient animal manure is not produced to cover the land, however, and other sources of organic matter such as stalks, straw, and chaff must be used along with leguminous green-manure crops.

In connection with the application of organic matter, they point out that an important distinction between kinds of organic matter



FIGURE 5.—It is often possible to establish grass on abandoned cropland and improve it for future cropping. This is crested wheatgrass (*Agropyron cristatum*) seeded at 4 pounds per acre in November 1933 on land abandoned in 1929, after the annual grass and weed cover had been burned in early summer. The picture was taken in May 1938 in Adams County, Wash., where the rainfall is very light.

with respect to chemical make-up has come to be recognized within the last few years. Excessive applications of straw or similar materials are likely to produce a depression in crop growth, which may lower the yield; they may produce unfavorable physical effects from incorporating decay-resistant material, particularly if dry weather ensues; and they also may bring about a detrimental chemical effect. Large quantities of cellulose stimulate the activities of certain microorganisms, so that they actually compete with the growing plants for nitrates. Heavy applications of straw or other cellulose materials should be plowed under with a good growth of legumes, or should be applied when they do not interfere with crops having large nitrate requirements.

Browning (19, p. 95) states that organic matter applied to soils of relatively poor structure increased the number of larger sized aggregates and decreased the dispersion ratio. When applied to soils containing considerable quantities of colloidal material, it made no appreciable changes in dispersion and aggregation but infiltration and percolation rates increased significantly.

He brings out the fact that intense cultivation for 15 years reduced the organic content of the soil from 3.5 to 2.0 percent and materially reduced the number of large-size aggregates and the infiltration capacity of the soil below that of an adjoining area in good bluegrass sod. Fertilizing a poor pasture has increased the organic content of the soil from 2.8 to 3.7 percent.

He emphasizes the importance of organic matter in relation to erosion control through the development and maintenance of desirable structural conditions of the soil.

Peele (95), in working with Cecil clay soil, finds that applications of lime have a dispersing effect on soil aggregates and render this soil less permeable to water. Percolation rates are increased by the addition of organic matter. Applications of lime to Cecil clay increase soil erodibility whereas additions of organic matter decrease it, although the beneficial effects of organic matter may overbalance the detrimental physical effects of lime.

Stauffer (115) points out that although many studies show conclusively that poor soil management is accompanied by reductions in plant nutrients and crop yields, more information concerning the effect of systems of cropping on the physical properties of the soil is needed.

In his opinion, the Morrow plots at the Illinois Agricultural Experiment Station, at Urbana, offer excellent information because the soil was apparently fairly uniform at the beginning of the experimental work, accurate records were kept over a long period, and very little erosion has taken place, the land being nearly level.

He states that the organic-matter content of the soil on the various plots, as measured by organic carbon, shows considerable variation. Where a corn-oats-clover rotation is followed and fertilizer is applied, the organic matter is higher than that in all other plots, and in the surface soil, higher than that in the grass border. The continuous-corn plot, without fertilizer, has the lowest organic-matter content. Excluding the surface soil layer, the grass border has the highest percentage of organic matter. In the surface soil (0 to 6½ inches) the lowest water-holding capacity and moisture equivalent, the lowest organic-matter content, and the highest dispersion and erosion ratios are found in the unfertilized continuous-corn plot, whereas the most rapid rate of percolation, the highest water-holding capacity and organic-matter content, and the lowest dispersion and erosion ratios are found in the limed, fertilized plot with a rotation of corn, oats, and clover.

He points out that under poor cropping systems soils are much more subject to destruction by erosion than under good cropping systems.

CROP SEQUENCE

In any cropping system, the order in which the crops are grown is of particular importance. Many a farmer has grown wheat following a heavy green-legume manure crop, only to lose his crop by lodging. Disappointing yields have been obtained in attempting to grow wheat, cotton, and other cash crops following sorghums, particularly in semi-arid regions or on droughty soils, because the sorghum almost completely removes the moisture from the soil. Potatoes following grass sod frequently are damaged by attacks of wireworms or white grubs. Many plant diseases can be perpetuated or increased by growing crops in the wrong order. Crop sequence is highly important not only in securing good crop yields, but in maintaining organic matter and essential plant-food elements, in controlling erosion and insect and plant diseases, and in saving labor and cost of production. The sequence of crops; the length of the rotation; the number of years each crop should be grown; the location of the fields, particularly those on sloping land; the methods of seeding; tilling and harvesting; and numerous other points need detailed study primarily in relation to soil maintenance.

Several interesting and worth-while experiments dealing with crop sequence have been conducted by experiment stations, and some of the most pertinent findings in relation to the use of grass in the rotation are reviewed here. Grass or grass-legume sod is remarkably resistant to erosion, and very little washing or blowing occurs on sodland that has been in cultivation for no more than 2 or 3 years, if the soil is not too sandy. On the contrary, such legumes as red clover, sweetclover, and soybeans, when plowed under, often leave the soil loose and flaky, so that it blows or washes badly. Crop sequence on erodible soils should be given all possible consideration, and grass or grass-legume mixtures should precede row crops in the rotation wherever such arrangement is possible and practical.

Hughes and Henson (62) report slightly better yields of corn in Iowa when it is grown in rotation with Sudan grass than when preceded by either soybeans or oats. In this experiment, all the crops were removed except the cornstalks and no fertilizer or manure was applied. The yields are given in table 6.

TABLE 6.—*Yield of corn when grown in rotation with oats, Sudan grass, and soybeans. (Iowa Experiment Station)*

Rotation	Yield per acre (air-dry)	Stand; stalks per hill	Percentage of moisture in the corn at harvest
	<i>Bushels</i>	<i>Number</i>	<i>Percent</i>
Corn and oats.....	56.4	3.78	38.7
Corn and Sudan grass.....	59.7	3.74	34.7
Corn and soybeans.....	57.9	3.90	31.2

Data from Hughes and Henson, Crop Production . . . , table 963 b, p. 758.

The results of experiments on crop sequence conducted at Cornell University are reported by Lyon (74) in table 7.

Lyon points out that this experiment demonstrates the superiority of clover as a source of available nitrogen, particularly the first year

TABLE 7.—*Yields of crops following red clover, timothy, and rye, respectively*
[The figures are for acre yields]

Succeeding crops	Crops on plats in 1920					
	Red clover	Unit	Timothy	Unit	Rye	Unit
1921 Oat grain.....	98.7	Bushels.....	43.7	Bushels.....	53.4	Bushels.
Oat straw.....	1.8	Tons.....	.7	Tons.....	1.1	Tons.
1922 Wheat grain.....	36.7	Bushels.....	37.7	do.....	24.2	Bushels.
Wheat straw.....	2.7	Tons.....	2.3	do.....	1.6	Tons.
1923 Corn fodder.....	3.7	do.....	3.4	do.....	3.5	Do.
1924 Wheat grain.....	34.5	Bushels.....	29.3	Bushels.....	31.5	Bushels.
Wheat straw.....	1.5	Tons.....	1.1	Tons.....	1.4	Tons.

Data from New York (Cornell) Agricultural Experiment Station Bull. 447, table 1, p. 5.

after it has been grown. Timothy decomposes slowly but by the second year produces a good effect.

Lyon also gives some useful information concerning plots that were seeded in 1913 to alfalfa and to timothy. The stand of alfalfa had become thin and weedy by 1921, although the land had been limed; and both the timothy and the alfalfa were plowed under in the spring of 1922. Corn was planted that year, followed by oats in 1923 and wheat in 1924. A comparison of the yields of these crops demonstrates that alfalfa exerts a much greater effect than timothy on the yields of subsequent crops, although the principal difference is noticeable the first year following plowing down the alfalfa.

As indicated in table 8, the stimulative effect of alfalfa on subsequent yields of other crops is outstanding the first year, showing an increase of 24 bushels of corn per acre over yields following timothy. By the third year after sod was broken, however, wheat following alfalfa outyielded wheat following timothy only 3½ bushels per acre. The timothy sod is able to maintain a more constant level of fertility, as evidenced by the yields of the crops following it. It is unfortunate that comparable yields of corn, oats, and wheat following an alfalfa-timothy mixture planting are not available.

TABLE 8.—*Yields of crops following alfalfa and timothy, respectively, when the meadows have remained down for several years*

[The figures are for acre yields]

Succeeding crops	Crops on plats in 1913-1921			
	Alfalfa	Unit	Timothy	Unit
1922 Corn ears.....	80.3	Bushels.....	54.1	Bushels.
Corn stover.....	5.7	Tons.....	3.5	Tons.
1923 Oat grain.....	73.7	Bushels.....	62.8	Bushels.
Oat straw.....	1.0	Tons.....	0.9	Tons.
1924 Wheat grain.....	39.6	Bushels.....	36.0	Bushels.
Wheat straw.....	2.0	Tons.....	1.9	Tons.

Data from New York (Cornell) Agricultural Experiment Station Bull. 447, table 3, p. 6.

Hartwell and Damon (51) report a Rhode Island experiment designed to study crop sequence in which 16 different crops were grown for 2 seasons and one of the crops was grown the third year over the entire area occupied by all 16 the 2 previous years.

In this experiment, soil tests were made to determine the plant-food needs of the crops, and these were supplied by application of fertilizer chemicals. No manure was used.

In 1910 onions were planted over the entire area. Following timothy with redtop, and redtop alone, the onions produced 406 to 412 bushels per acre; following squash, timothy, and alsike clover, 240 to 314 bushels; following corn, millet, onions, oats, and red clover, 131 to 178 bushels; following potatoes and rye, 35 to 87 bushels; and following cabbages, mangrel beets, rutabaga turnips, and buckwheat, 13 to 17 bushels per acre.

Buckwheat was used in 1913, after the 16 crops had again been grown 2 years, to determine the effect of crop sequence. The buckwheat produced 34 bushels per acre following turnips, and only 4 to 10 bushels following clovers, corn, grasses, and millet. Intermediate yields were obtained following all the other crops.

In 1916 and 1917 alsike clover was grown over the entire area; and the highest yields of hay, 4.16 to 4.33 tons per acre, were obtained following rye and redtop and 2 years' failure of squash. The lowest yields were 2.53 to 2.60 tons following the clovers and carrots. Yields ranged from 3.31 to 3.86 tons per acre following all the other crops.

Hartwell and Damon determined the nutrients removed by some of the crops and conclude that the crops that exert the most depressing effect on a following crop are not always those that remove the largest quantity of the scarcest nutrients from the soil.

On this same line of work, Odland and others (92) reported the yields of four crops following some of the grasses and clovers. The yields following redtop, timothy, alsike clover, and red clover are shown in table 9. An explanation of the variation in yield possibly lies in the differences in organic matter in the soil, as is suggested in the following quotation (92, p. 32).

TABLE 9.—*Yields of corn, rutabagas, mangels, and potatoes per acre following 4 years of redtop, timothy, alsike clover, and red clover*

Previous crop	Corn	Rutabagas	Mangels	Potatoes
	<i>Bushels</i>	<i>Bushels</i>	<i>Tons</i>	<i>Bushels</i>
4 years redtop.....	101.0	673.9	23.85	432.0
4 years timothy.....	98.3	622.6	21.60	396.5
4 years alsike clover.....	101.1	584.0	17.55	327.0
4 years red clover.....	100.9	504.3	16.12	325.5

Data from Rhode Island Agricultural Experiment Station Bull. 243, table 4, p. 12.

There are the possibilities associated with the organic residues of the soil and different rates of removal of nutrients, either organic or inorganic in nature. No local experiments on organic residues as causes have reached a successful conclusion, thus far, but such factors are of unquestionable importance.

Leighty (70, pp. 415-416) lists 24 plant diseases that are controlled entirely or in part by means of crop rotation, and resistant or immune crops are named. It is significant that alfalfa wilt can be controlled by maintaining short stands of 3 or 4 years, since this encourages the use of alfalfa in rotation with other crops, a practice highly desirable for soil maintenance. Cotton root rot can be controlled by growing grasses, grains, corn, and sorghum for 3 years

before returning to cotton for a similar period (fig. 6). From the data given, it is apparent that the use of proper crop rotations will go a long way in controlling certain plant diseases that undoubtedly have been increased and intensified by the practice of one-crop production in different sections of the country in past years.



FIGURE 6.—The cotton on the left, in a field in Arkansas, followed cotton and that on the right followed cowpeas, which were seeded after winter oats. The introduction of grain into the rotation decreased infestation of root rot. The cotton following cotton yielded 203 pounds per acre; that in rotation, 279 pounds. The man is comparing the height of continuous and rotation cotton.

CROP-ROTATION EXPERIMENTS AT SOIL AND WATER CONSERVATION EXPERIMENT STATIONS

Considerable information relative to the soil and water losses under crop rotations in comparison with continuous production of corn, cotton, kafir, wheat, and other crops is available at several soil and water conservation experiment stations. A summary of this information is given in table 10. The benefit of crop rotations alone in reducing soil and water losses is remarkable. If crop rotations are combined with contour cultivation, contour strip cropping, terracing, and proper use of crop residues, losses can be reduced to a minimum.

The rotations used in the experiments are those that have been recommended by experiment stations and widely used by farmers. Undoubtedly others including grass or grass-legume mixtures would give better erosion control. Limited funds prevented the inclusion of a larger number of rotations in the studies at the time they were begun.

Weaver and Noll (128) give data relative to soil and water losses from studies conducted on prairie, pasture, and cultivated land in

TABLE 10.—*Results of soil and water losses under various crop rotations as compared with continuous cropping at several soil-erosion experiment stations*

[Rainfall figures are averages for length of experiment only]

Crops compared	Location	Slope of plots	Soil type	Average precipitation	Average run-off	Average erosion per acre	Density of run-off ¹
Continuous cotton	Guthrie, Okla. (1930-35 summary).	Pct. 7.7	Vernon fine sandy loam.	In. 33.12	Pct. 14.31	Tons 24.29	37.75
Cotton, wheat, sweet-clover rotation.	do.	7.7	do.	33.12	11.60	5.54	10.64
Continuous corn	Temple, Tex. (1931-35 summary).	3.75	Houston black clay loam.	31.34	13.72	20.89	35.77
Corn, oats, cotton rotation.	do.	3.75	do.	31.34	7.71	10.41	31.72
Continuous kafir	Hays, Kans. (1930-35 summary).	5	Colby silty clay loam.	20.36	16.20	11.75	26.22
Wheat, kafir, fallow rotation.	do.	5	do.	20.36	14.86	8.26	20.11
Continuous wheat	do.	5	do.	20.36	10.69	2.25	7.61
Continuous corn	Bethany, Mo. (1931-35 summary).	8	Shelby loam	34.79	28.31	68.78	51.43
Corn, wheat, clover rotation.	do.	8	do.	34.79	15.23	11.35	15.78
Continuous cotton	Tyler, Tex. (1931-34 summary).	8.75	Kirvin fine sandy loam.	40.52	19.52	19.08	17.76
Cotton, corn, lespedeza rotation with oats as winter cover.	do.	8.75	do.	40.52	17.64	14.40	14.83
Continuous cotton	Statesville, N. C. (1931-35 summary).	10	Cecil sandy clay loam.	45.22	10.21	22.58	36.00
Wheat, lespedeza, cotton, and corn rotation.	do.	10	do.	45.22	8.97	10.61	18.61
Winter wheat, summer fallow.	Pullman, Wash. (1932-35 summary).	230	Palouse silt loam.	21.74	8.93	8.52	32.31
Peas and sweetclover, sweetclover, winter wheat, spring wheat rotation.	do.	230	do.	21.74	10.02	7.85	26.55
Continuous corn	Clarinda, Iowa (1933-35 summary).	9.6	Marshall silt loam	26.82	8.64	18.82	59.84
Corn, oats, clover rotation.	do.	9.6	do.	26.82	4.95	5.40	29.96
Continuous corn	Lacrosse, Wis. (1933-35 summary).	16	Clinton silt loam	34.12	20.58	88.35	92.68
Corn, clover, barley rotation.	do.	16	do.	34.12	12.07	25.31	45.28
Continuous barley	do.	16	do.	34.12	15.46	14.19	19.81
Continuous corn	Zanesville, Ohio (1934-35 summary).	12	Muskingum silt loam.	34.51	35.18	59.62	36.17
Corn, wheat, 2-years grass rotation.	do.	12	do.	34.51	18.45	7.95	9.19

¹ Pounds of soil lost per 100 gallon water run-off.² South.

MUSGRAVE, G. W. SUMMARY OF SOIL WATER LOSSES AT SEVERAL EROSION-CONTROL EXPERIMENT STATIONS. U. S. Soil Conserv. Serv. 1935. [Mimeographed.]

Nebraska in 1934 and 1935. Natural rainfall was supplemented by artificial watering in the experiments.

Over a 15-month period, run-off from 26.88 inches of rainfall on Carrington silt loam with a 10° slope was 15.1 percent from a badly overgrazed pasture, 9.1 from overgrazed pasture and 2.5 from prairie. From the practically bare pasture, 5.08 tons of soil per acre were lost, and minor amounts from the prairie and overgrazed pasture.

Water applied to prairie, pasture, and bare areas in April and again in October 1935 resulted in heavy run-off and soil losses from the bare area, medium from the pasture, and practically no run-off or soil loss

from the prairie. Weaver and Noll state that the water penetration in the prairie was nearly four times as great as in pasture.

They point out that a good cover of grass is insurance against erosion, whereas overgrazing or cultivation invariably results in losses. These can be repaired by nature if too much soil has not been lost. Pasture improvement is recommended as a chief weapon against erosion.

They state: "A soil covered with its natural mantle of climax vegetation represents conditions most favorable to maximum absorption of rainfall and maximum erosion control."

CROP ROTATION EXPERIMENTS AT STATE AND FEDERAL EXPERIMENT STATIONS

In this review of the literature dealing with crop rotation in the United States, an attempt has been made to compile the information pertinent to erosion control by regions that follow in general the great soil groups outlined by Baldwin, Kellog, and Thorp (*7*, pp. 979-1001). These regions² are (1) the northern Great Plains, primarily Cherozenom, Chesnut, and some Prairie soils; (2) the Corn Belt, largely Prairie and Gray-Brown Podzolic soils; (3) the Northeastern States, Podzolic and Gray-Brown Podzolic soils; and (4) the Southeastern States, Red and Yellow Podzolic soils. Very little experimental information is available on soil-conserving rotations for the Desert soils and other soil groups in other sections of the country.

NORTHERN GREAT PLAINS

Sarvis and Thysell (*110*), from 20 years' results of crop-rotation experiments at the Mandan, N. Dak., experiment station, conclude that mixed farming is much less hazardous than straight grain farming in regions of low rainfall where irrigation is not possible. The authors give considerable information concerning tillage and cropping practices, and they recommend spring plowing for corn as the most desirable practice of those tried in the experiment. Summer fallow and land in corn are advisable for wheat and other small grains. Subsoiling has not increased yields and requires more labor. Therefore it is not recommended. On soils that may be a blow hazard, spring listing is advocated.

Such crops as alfalfa, sorgo, brome-grass, potatoes, and green-manure crops are grown in rotation with other crops each year in order to study the effect of crop sequence. Alfalfa, although winter killing has occurred frequently, has averaged three-fourths of a ton of hay per acre; brome-grass has yielded less than half as much as alfalfa.

The authors conclude that better tillage methods, if generally adopted, would give higher and more uniform yields of crops and would improve the quality.

² The work in Washington has been discussed in the section Losses in Soil Organic Matter. Idaho Agricultural Experiment Station Bulletin 227, Crop Rotation Studies, had not been published at the time this manuscript was prepared. The results of crop rotations in Oregon have not been published. Therefore in this section there is no discussion of the Pacific Northwest region.

McKee (78) states that alfalfa in the crop rotation on irrigated land will maintain high crop yields if grown at least 3 years in succession and will also prevent noxious weeds from becoming a menace to farming operations. He also points out that manure applied regularly to one crop in the rotation increases the yield of all crops.

Moomaw (83) summarizes the results of rotation experiments conducted at points in western North Dakota by stating that the results of most of the experiments (dry-land farming) are very similar to those secured by other northern Great Plains experiment stations.

He gives considerable information of a pertinent nature concerning tillage practices and crop sequence that show their importance in successful crop production. Fallow, in addition to increasing crop yields, is of great value in weed control and in facilitating early seeding. The use of corn in the rotation also allows early seeding of small grains since the cornland requires very little preparation for seeding, and small-grain crops give excellent yields following corn. It is apparent that the use of corn in the rotation is far beyond the value of the corn crop.

In line with Sarvis' conclusions, Moomaw finds that manure or green-manure crops do not increase crop yields. He states that a legume crop for green manure is of no more value than a nonlegume, and no cumulative effect is apparent.

Moomaw points out that a marked reduction in yield of small grains occurs when they are grown continuously and feels the reduction is attributable to weeds rather than to loss of soil fertility.

Cole (23), in discussing the results of crop rotation and cultural methods at Edgeley, N. Dak., after 15 years of experimentation, concludes that successful farming depends on good husbandry and attention to numerous details. He also points out the importance of weed control, timely field operations, quality of field work, and the use of good seed.

Cole recommends both alfalfa and brome-grass as sod crops, and he particularly recommends brome-grass as a reliable hay crop well suited to short rotations. Alfalfa has not yielded as heavily as brome-grass and has been subject to rather infrequent winter killing, but the hay is of higher value than brome-grass hay. He recommends seeding brome-grass with a nurse crop, but alfalfa should be seeded alone.

He shows that alfalfa has depressed the yield of subsequent crops when used in dry-land farming. Brome-grass has depressed the yield of the first crop produced after it but apparently has not affected later crops.

Cole feels that sod crops do enter into the rotation and should be broken up and reseeded as necessary in order to produce maximum yields of the sod crops.

Hastings (56, p. 34), in summarizing the results from irrigated-crop rotations conducted at the Scotts Bluff, Nebr. Field Station, gives the following data on economic aspects of several cropping systems. The figures given are 23-year averages and represent net returns per acre for the 32 cropping systems listed. It will be noted that several show a loss, indicated by the minus sign.

Crops, treatments, and sequences:	Net return per acre
Sugar beets (manure), potatoes-----	\$28. 23
Oats (with sweetclover), sweetclover pastured, sugar beets (2 years)	24. 26
Alfalfa (3 years), potatoes, sugar beets (manure), sugar beets, oats---	21. 45
Oats (manure), sugar beets-----	21. 32
Alfalfa (2 years), potatoes, sugar beets-----	21. 05
Potatoes, oats (manure), sugar beets-----	20. 86
Alfalfa (3 years), potatoes, oats (manure), sugar beets-----	20. 44
Alfalfa (3 years), potatoes, sugar beets, oats-----	19. 15
Alfalfa (3 years), potatoes, oats, sugar beets-----	13. 11
Oats (manure), potatoes-----	8. 91
Alfalfa continuously-----	7. 60
Alfalfa (3 years), corn, oats, sugar beets-----	6. 95
Alfalfa (2 years), oats, sugar beets-----	6. 78
Alfalfa (2 years), potatoes, oats-----	4. 46
Potatoes, oats, sugar beets-----	2. 55
Oats, (rye plowed under), potatoes-----	. 90
Sugar beets, potatoes-----	. 65
Oats, sugar beets-----	. 13
Spring wheat, sugar beets-----	— . 39
Corn, oats, sugar beets-----	—1. 26
Alfalfa (2 years), spring wheat, oats-----	—3. 10
Sugar beets continuously-----	—4. 71
Oats, potatoes-----	—5. 09
Corn, oats-----	—6. 53
Potatoes, corn-----	—7. 66
Corn continuously-----	—8. 07
Oats continuously-----	—10. 01
Spring wheat, oats-----	—11. 83
Winter wheat continuously-----	—12. 03
Spring wheat continuously-----	—13. 05
Spring wheat, straw returned-----	—13. 17
Potatoes continuously-----	—28. 08

Gross and Doll (45), in reporting results of experimental work in Nebraska, state that organic matter is added to the soil and crop yields are increased by the use of legumes and grasses in the rotation. The improvement in soil organic matter and the physical structure of the soil lessen both soil and water losses through erosion and run-off.

They cite the results of a 6-year experiment comparing soil and water losses from continuous corn with those from a rotation of corn, wheat, and a clover-grass mixture on land of glacial origin. During the 6-year period, the continuous cornland lost 233 tons of soil and 55 percent more water per acre than the land in rotation.

Zook (148), writing about the dry-land experimental cropping practices at North Platte, Nebr., points out that winter wheat following corn is apparently more profitable than winter wheat following fallow, since each bushel of wheat gained by conserving moisture through fallowing was offset by 2.4 bushels of corn. His results show clean fallow to be superior to weedy fallow for wheat production, however, the average yield of wheat after clean fallow being 30 bushels per acre and after weedy fallow 22.2 bushels. He also found that green-manure crops deplete the soil moisture sufficiently to offset any gain in fertility.

CORN BELT

Walker and Brown (126) point out that soil losses from Iowa are tremendous, especially under certain soil exposures. They have calculated the average loss of soil potassium, nitrogen, and phosphorus,

respectively, from 160 acres as a unit of area, to have been 2,046, 247, and 82 tons.

In pointing out that nature's method of erosion control is ideal and should be used as a basis for planning soil-management practices they recommend the production of sod crops at regular intervals and set up rather definite and highly commendable policies on soil management based on proper land use. They recognize the importance of crop rotation and the necessity of fitting the rotation to the particular soil; the need of limestone; the value of adapting cultivation practices to the erosion-control needs; the use of manure, crop residues, and green-manure crops to improve the water-holding and absorptive capacity of the soil; and the use of fertilizers to supply needed plant nutrients and thus secure more vegetal cover.

Stevenson, Brown, and Forman (117), in comparing rotations over a 10-year period, conclude that a 3-year rotation of corn, oats, and clover yielded much greater economic returns than a 2-year alternation of corn and oats or the growing of corn continuously on typical Wisconsin drift soil. They also point out that the inclusion of alfalfa for a 5-year period in a rotation including corn, oats, clover, and wheat, increased the income over the 3-year rotation of corn, oats, and clover when both were treated with manure and lime but not under all treatments that were tried.

They conclude that a 4- or 5-year rotation may, over a period of time, be of more value than a 3-year rotation, but point out that the 3-year rotation is distinctly preferable to continuous cropping or to a 2-year rotation.

Hughes and Henson (62) have compiled results from annual reports of the Illinois experiment station and present yields from a 38-year experiment comparing (1) corn grown continuously; (2) a 2-year rotation of corn and oats; and (3) a 3-year rotation of corn, oats, and clover. The yields are given in table 11.

TABLE 11.—*Yield of corn grown continuously, in rotation with oats and with oats and clover, Illinois*

Average of years	Corn every year	Two years		Three years		
		Corn	Oats	Corn	Oats	Clover
1888 to 1903, 16 years.....	39.7	41.0	44.0	48.0	47.6	2.03 T.
1915-26, 12 years.....	24.0	34.0	33.0	43.0	55.0	1.9 T.

Data from Hughes and Henson, Crop Production . . . , table 959a, p. 750.

Using the 1915-26 average yields given in this table for calculations, 30 acres of continuously grown corn would produce 720 bushels. The 2-year rotation, namely, 15 acres of corn and 15 acres of oats, would produce 758 bushels of corn equivalent, at a less cost per bushel. The 3-year rotation, namely, 10 acres of corn, 10 acres of oats, and 10 acres of clover, would produce 1,065 bushels of corn equivalent, at a still lower cost per bushel, and in addition, would add materially to the soil-conserving value of the cropping system.

Wiancko, Mulvey, and Miles (136), from results of experiments with crop rotations, report that the work is giving practical information on the adaptability of crop rotations to central and part of north-

eastern Indiana, since the soil under this experiment is representative of most of the farms in this section. The data shown in table 12, therefore, are of considerable significance.

These investigators also state that rotating alfalfa with grain crops has brought the largest return mainly because of good yields of high-value alfalfa hay. According to this table, the 3-year rotation of corn, wheat, and alfalfa (No. 4) has produced an average return of \$30.90 per acre, and the 6-year rotation of corn, corn, wheat, and 3 years of alfalfa (No. 10) has averaged \$30.82 per acre. It will be noted that fertilizer and manure charges have been deducted.

TABLE 12.—*Results of comparison of cropping systems (central Indiana)*

Crop rotations or cropping systems	Corn per acre by periods		Wheat or oats per acre by periods		Soybeans per acre by periods		Hay per acre by periods		Average annual return per acre ¹
	1916-1924	1925-1936	1916-1924	1925-1936	1916-1924	1925-1936	1916-1924	1925-1936	1925-1936
	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Bushels</i>	<i>Pounds</i>	<i>Pounds</i>	<i>Dollars</i>
1. C. W. Cl.-----	49.4	58.8	24.3	27.1	-----	-----	3,862	4,814	24.89
2. C. O. Cl.-----	56.8	61.4	45.7	43.2	-----	-----	3,394	3,868	20.29
3. C. C. W. Cl.-----	53.8	54.9	22.2	29.3	-----	-----	3,747	4,029	24.50
2nd corn.-----	46.0	48.3	-----	-----	-----	-----	-----	-----	-----
4. C. W. A.-----	56.9	60.7	23.8	29.0	-----	-----	5,081	6,770	30.90
5. C. S. W. (Sw. Cl.)-----	48.3	55.8	32.1	32.6	19.4	28.5	-----	-----	29.44
6. C. W. Sw. Cl.-----	53.6	56.9	26.9	27.3	-----	-----	3,203	2,843	22.07
7. C. S. W. Cl.-----	58.8	61.7	31.3	33.5	20.4	26.7	3,821	4,218	26.69
8. C. W. Cl. T.-----	58.7	59.3	24.7	27.1	-----	-----	8,718	8,707	22.39
9. C. C. S. W. Cl.-----	59.3	60.2	33.0	33.5	20.9	28.3	3,805	4,231	27.63
2nd corn.-----	54.3	56.6	-----	-----	-----	-----	-----	-----	-----
10. C. C. W. A. A.-----	62.6	63.7	31.5	32.8	-----	-----	21,102	20,749	30.82
2nd corn.-----	56.2	58.7	-----	-----	-----	-----	-----	-----	-----
11. Continuous wheat.-----	-----	-----	-----	24.4	-----	-----	-----	-----	21.35
12. Continuous oats.-----	-----	-----	-----	45.6	-----	-----	-----	-----	13.07
13a. Corn, oats, (Sw. Cl.)-----	-----	56.0	-----	46.9	-----	-----	-----	-----	21.94
13b. Corn, oats.-----	-----	52.8	-----	43.8	-----	-----	-----	-----	20.45
14. Continuous corn.-----	-----	39.7	-----	-----	-----	-----	-----	-----	20.58

¹ After deducting cost of fertilizer and 50 cents per ton for spreading manure. Fertilizer is charged at \$1.38 per acre per year in cropping systems 1, 2, 3, 4, 5, and 6; \$1.05 in 7, 8, and 9; \$3.08 in 10; \$2.89 in 11 and 12; \$3.06 in 13a and 13b; and \$3.24 in 14.

C.=Corn. W.=Wheat. O.=Oats. Cl.=Clover. S.=Soybeans. Sw. Cl.=Sweetclover. (Sw. Cl.)=Sweetclover intercrop. A.=Alfalfa. T.=Timothy.

Data from Indiana Agricultural Experiment Station, Report of Progress 1915-36, table 1, p. 3.

These authors feel that the 5-year rotation of corn, corn, soybeans, wheat, and clover is very well adapted for good land, as in this experiment, and is more practical for most farmers than the alfalfa rotations (Nos. 10 and 4). For farms where little or no livestock is kept, the 3-year rotation of corn, soybeans, and wheat, with sweetclover seeded in the wheat as an intercrop (No. 5), is felt to be suited to the land under experiment and is the most profitable grain-cropping system.

They also point out that corn yields cannot be maintained as effectively where one-half or more of the land is in corn as where the acreage of corn is reduced to only one-third or two-fifths by using longer rotations.

They report an experiment to determine whether grain farming and the substitution of commercial fertilizers and crop residues for manure can maintain the soil fertility as well and be as profitable as livestock farming.

On the grain-farming plots, the soybean straw was used to top-dress the wheat in winter, the wheat straw was applied to alfalfa sod and

plowed under preceding corn, and the cornstalks were plowed under preceding soybeans, whereas on the livestock-farming plots all the roughage was removed, and the manure applied was equivalent, by weight, to all produce harvested except the wheat grain. The results are given in table 13.

TABLE 13.—*Results of comparison of grain and livestock systems of farming (central Indiana)*

Plot Number	Treatment	Average yields per acre				Financial statement per rotation			
		Corn 1924- 1936	Soy- beans 1924- 1936	Wheat 1924- 1936	Hay 1924- 1936	Total value of grain and hay	Increase due to treat- ment	Cost of treat- ment	Gain over cost of treat- ment
		<i>Bu.</i>	<i>Bu.</i>	<i>Bu.</i>	<i>Lbs.</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Dollars</i>
1	Res. check.....	56.1	29.8	25.7	4,341	110.87			
2	Res. P.....	57.3	30.5	31.4	4,584	119.20	23.45	7.20	16.25
3	Res. PK.....	63.1	32.5	32.2	4,831	126.72	30.61	10.08	20.53
4	Res. check.....	57.6	30.9	24.3	4,438	111.95			
5	Res. NPK.....	63.4	31.9	33.3	4,883	127.66	31.99	11.04	20.95
6	Res. NPK+N.....	63.2	31.7	35.6	4,847	129.46	34.59	12.52	22.07
7	Untreated.....	44.9	26.2	21.3	3,926	94.07			
8	Manure.....	68.4	30.2	30.2	4,894	125.91	32.64	4.58	28.06
9	M P.....	68.2	30.8	32.6	4,949	129.07	36.60	8.30	28.30
10	Res. check.....	57.3	28.9	22.1	4,354	107.15			
11	M PK.....	69.5	29.9	33.6	5,114	130.77	39.28	9.60	30.68
12	M NPK.....	70.1	31.0	35.8	4,988	133.80	42.50	10.61	31.89
13	Res. check.....	57.9	29.5	22.4	3,991	106.60			
	Average Res. checks.....	57.2	29.8	23.6	4,281	109.01	15.48		

Res.=cornstalks and straw left on the land; P=phosphoric acid; K=potash; and N=nitrogen in fertilizer; M=manure.

The basal fertilizer formula is 2-16-8 in the grain farming system and 2-12-6 in the livestock system.

The fertilizer is divided between the corn and wheat. Corn gets 100 pounds per acre in the hill on all fertilized plots and wheat gets 300 pounds. Before planting, corn also gets 200 pounds 0-16-0 on plot 2 and 200 pounds 0-16-8 on plots 3, 5 and 6. The wheat on plot 6 also gets 16 pounds of nitrogen per acre as a top dressing in the spring.

Data from Indiana Agricultural Experiment Station, Report of Progress 1915-1936, table 3, p. 6.

The authors state (136, p. 6):

The crop residues alone, averaging 3,458 pounds of cornstalks, 2,300 pounds of soybean straw, and 1,858 pounds of wheat straw, have produced crop increases averaging 12.6 bushels of corn, 3.7 bushels of soybeans, 1.9 bushels of wheat, and 470 pounds of hay per acre, or \$4.07 per ton of residues.

The manure equivalent of the roughage and grain other than wheat, averaging 9.2 tons per acre for each round of the rotation, has produced crop increases averaging 23.6 bushels of corn, 4.3 bushels of soybeans, 9.3 bushels of wheat, and 982 pounds of hay per acre, or \$3.55 per ton of manure (plot 8).

Hughes and Henson (62, p. 756) give the yields of wheat in the eighteenth year of a rotation experiment in which it is possible to compare the effect of grass, of clover, and a mixture of both, as the other crops in the rotation are the same. Corn, oats, wheat, clover (second crop plowed under) produced 25.2 bushels of wheat per acre; corn, oats, wheat, grass produced 29.1 bushels; and corn, oats, wheat, clover, and grass produced 25.6 bushels. The advantage in this experiment is materially in favor of the grass.

Information concerning the organic-matter content of the soil in these plots would be very interesting in relation to soil maintenance and permanent cropping practices, considering the importance of soil organic matter in checking erosion and increasing the rate of infiltration of water into the soil.

Etheridge and Helm (40, pp. 7-8) recommend the use of Korean lespedeza with oats as a very practical rotation in Missouri. They

advise seeding the oats on Korean lespedeza sod each spring and point out that the lespedeza, under reasonable management, will volunteer and produce a stand in the oats for utilization after the oat crop has been harvested.

Detailed recommendations are given relative to tillage and management methods for perpetuating the system. The application of 125 to 150 pounds per acre of 20-percent superphosphate to the oats will increase the yields of both crops and is considered a profitable practice. The use of an early maturing variety of oats is essential to the success of this rotation, and it is recommended that the oats be cut for hay if the month of June is very dry and hot in order to get a good crop of lespedeza.

Etheridge and Helm state that a large annual return may be obtained from such a double cropping system. Pasturing the lespedeza will add nitrogen and organic matter to the soil; and applying super-

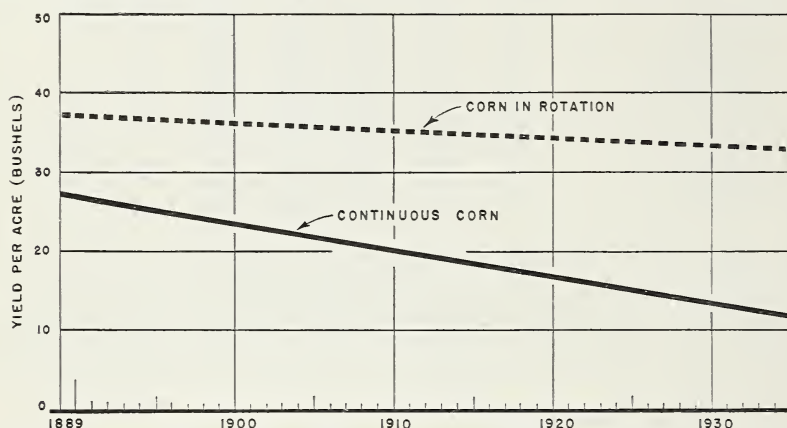


FIGURE 7.—Corn yield trends on Sanborn plots, Columbia, Mo.; continuous corn versus corn in rotation with small grain and clover.

phosphate to the oats will improve rather than reduce soil fertility, even though rather heavy production is maintained by the double cropping method.

Following a line of thought at considerable variance with this, a special committee of extension agronomists (2) recommends that the extent to which a sound soil conservation and soil-improvement program can be developed for the rotated and pasture land of the Northeastern and North Central States is limited chiefly by the speed with which acid soil can be limed. They state the program must be built on the use of certain effective erosion-control and soil-building legumes, and it is a well known fact that these legumes cannot be grown successfully on land of a certain degree of acidity. The committee adds (2, p. 1064):

Any attempt to side-step the liming of acid land in a long-time improvement program by promoting the growing of acid-tolerant legumes and grasses as soil-improving and soil-conserving crops is doomed to failure. The continued use of these crops to the exclusion of our more desirable soil-building legumes will only make a bad situation worse. The meager growth of these crops on strongly acid land will not materially build up the organic matter and nitrogen content of

the soil nor will it furnish feed efficiently. As a matter of fact, the continued growing of these crops under strongly acid conditions means continued soil deterioration.

Collier and Johnson (24) give some significant data from Missouri comparing the yield trends of continuous corn and corn in rotation with small grain and clover (fig. 7).

Moore (84), in commenting on the production of better quality potatoes in Michigan, recommends planting on soil that has ample organic matter with good drainage. The best crops for preceding potatoes that will add to the soil fertility and increase the water-holding capacity are alfalfa, sweetclover, and red clover. By planting potatoes following one of these crops, serious injury from white grubs and wireworms may be avoided. Moore points out that grass sods are often infested with wireworms and grubs. A long rotation, with potatoes on the same land only once in 4 or 5 years, is advisable in order to produce tubers free from disease.

Army (3), in discussing the results of crop-rotation experiments in Minnesota, states that rotations of grain, clover, and timothy hay, and tilled crops, using moderate amounts of manure, have with one exception returned net incomes of \$8.76 or more per acre and at the same time maintained yields. In growing timothy and other perennial grasses, annual cultivation is not practiced, consequently organic materials decay slowly. Army states that grass roots are so numerous that they aid materially in maintaining the supply of organic matter. The cropping systems that gave large net returns included corn, small grains, and timothy-clover sod in a 4- to 7-year rotation with light manuring. He points out that cropping systems have proved most practical when provision has been made to maintain organic matter by growing legumes, adding manure, or both.

NORTHEASTERN STATES

Lyon and Bizzell (76), in reporting results of crop-rotation work in New York, point out that soil productivity for grain crops is increased by applying fertilizer to timothy sod preceding the grain crops. Corn, which immediately followed timothy, gave the greatest response, oats the next greatest, and wheat the least.

Alfalfa and timothy were grown on adjoining plots of land for 6 years, after which the land was plowed and planted to corn the first year and to oats the second year. The corn produced a considerably larger yield following the alfalfa; the oats produced equally well following both alfalfa and timothy.

By analysis, Lyon and Bizzell found very little difference in the nitrogen content of the soil in the alfalfa plot and in the timothy plot, that of the former exceeding that of the latter by only 0.01 percent. Under incubation, however, nitrates formed more rapidly in the soil from the alfalfa plot. The authors feel that their data are not sufficient to show whether more nitrogen accumulated in the soil in the alfalfa plot than in that in the timothy plot or whether the ready availability of nitrogen in the former rather than the larger quantity of it might be responsible for the greater productivity of this soil.

Lyon (75, pp. 15-16), in reporting on the residual effects of leguminous crops, points out that alfalfa increased the yield of subsequent cereal crops more than any other legume. Practically equal results were obtained following sweetclover, red clover, and alsike clover. A much less favorable response was obtained following soybeans and field beans, vetch grown with wheat, and peas with oats. However all the legumes did give a response by increasing yields of subsequent crops over those in rotations without legumes.

Lyon shows that there was a great variation in the production of dry matter by the several legumes. Alfalfa produced more than double the yields of the clovers, and soybeans also outyielded them, as did the vetch and wheat mixture. Red and alsike clover grown in mixture gave a higher yield than either grown alone, while the mixture of peas and oats gave the lowest yield.

It is significant that the annual legumes in the experiment, with the exception of soybeans, produced less total digestible nutrients in the rotations than the biennial or perennial legumes, and the annual legumes had less effect on the nitrogen content of succeeding crops, which Lyon states may be due to the extent of root systems, growth at harvest time, and the period of time the legumes were on the land. From determinations of soil nitrogen made at the beginning and at the end of the experiment, it is possible to show gains or losses in nitrogen (table 14). Lyon points out that the amount of nitrogen in the leguminous crops is not always directly related to the accumulation of soil nitrogen.

TABLE 14.—*Gains or losses of soil nitrogen during the period covered by the experiment, and amounts of nitrogen contained annually in the nonleguminous crops*

Kind of legume in the crop rotation	Gain or loss of soil nitrogen per acre	Nitrogen in non-leguminous crops per acre
	<i>Pounds</i>	<i>Pounds</i>
Red clover.....	+532	50.9
Alsike clover.....	+595	48.8
Alfalfa.....	+607	66.4
Sweet clover.....	+420	51.0
Red clover and alsike clover.....	+577	53.5
Sweet clover and vetch.....	+410	51.2
Soybeans.....	-42	28.7
Field beans.....	-100	24.8

Data from New York (Cornell) Agricultural Experiment Station Bull. 645, table 10, p. 14.

He points out that the accumulation of nitrogen in the soil, as shown in table 15, can hardly be classed as definitely the result of the nitrogen produced by the legumes grown. There is very little difference in the amount of nitrogen contained in the various legume crops. Alfalfa leads, with soybeans second, followed by sweetclover and the mixture of red and alsike clover. On the other hand, it seems clear that the lesser amounts of nitrogen in the cereal crops following the annual legumes can be laid to actual nitrogen losses in the soil.

Prince, Toth, and Blair (101), in reporting soil studies made in New Jersey, state that changes in the chemical composition and physical structure of soil over a 24-year period on cultivated land and on land abandoned to grass and weeds show an accumulation of both nitrogen

and carbon on the abandoned land of 27 and 38 percent, respectively, and a loss on the cultivated land of 1 and 10 percent, respectively. Both areas were fertilized annually. A detailed study was conducted, including various fertilizer applications and soil analyses for various elements. Over a 28-year period the carbon content of abandoned land has increased approximately 6 tons per acre.

TABLE 15.—*Gains or losses of soil nitrogen during the period covered by the experiment, and average nitrogen content of the leguminous crops*

Kind of legume in the crop rotation	Gain or loss of soil nitrogen per acre	Nitrogen in leguminous crops per acre
	<i>Pounds</i>	<i>Pounds</i>
Red clover.....	+532	114.2
Alsike clover.....	+595	109.1
Alfalfa.....	+607	298.9
Sweet clover.....	+420	169.2
Red clover and alsike clover.....	+577	151.5
Sweet clover and vetch.....	+410	146.9
Soybeans.....	-42	176.1
Field beans.....	-100	103.0

Data from New York (Cornell) Agricultural Experiment Station Bull. 645, table 11, p. 15.

Wheeler and Tillinghast (133), reporting on rotation work in Rhode Island in 1900, state that soil shows marked physical improvement if a grass or clover sod is plowed under occasionally. Nine years later, Wheeler and Adams (132), reporting on the same work, credit the benefit derived to the incorporation of vegetable matter into a soil that already contains a large quantity of coarse, partly decayed vegetable matter rather than to the increase in humus.

Hartwell and Damon (50), report a 20-year comparison of different rotations of corn, potatoes, rye, and grass, in Rhode Island, extending 3, 4, 5, and 6 years. They found that the inclusion of legumes as a cover crop did not show superiority to rye in potato production.

Holder and Hunter (59) recommend that in growing beans in Maryland a 4- or 5-year rotation be followed to maintain soil fertility and help to control diseases. Cover crops or green-manure crops are recommended as particularly important, owing to the limited supply of barnyard manure available. They suggest the use of such crops as rye, wheat, and legumes and recommend the following rotations for localities where there is intensive production of canning crops.

First year—Tomatoes, followed by rye.

Second year—Peas, followed by lima beans; rye seeded in fall.

Third year—Sweet corn, followed by rye or crimson clover.

Fourth year—Snap beans, followed by winter barley.

Fifth year—Winter barley, cut for feed, seeded to timothy and alsike clover.

They recommend the substitution of snap beans for a portion of the corn acreage where a corn-wheat-hay rotation is practiced, advising the use of winter barley as a feed crop following the beans.

SOUTHEASTERN STATES

Data on crop-rotation experiments particularly adapted to erosion control in the Southeastern States are few, but there is sufficient information to demonstrate the possibilities of using crop rotations.

as a means of erosion control. Some excellent information from Virginia ³ shows considerable income from good soil-conserving rotations. On Cecil clay loam in Appomattox County, a 4-year rotation of tobacco (dark), wheat, clover and grass 2 years returned more net profit per acre per year (\$15.87) than 4-year rotations of tobacco (crimson clover and rye cover crop), soybeans, wheat, and red clover (\$11.29), or corn, wheat, clover and grass 2 years (\$13.55) when each of these rotations was fertilized with a 3-8-3 fertilizer at the rate of 1,000 pounds per acre.

These data from the Virginia station show that the application of 1,000 pounds per acre of superphosphate to 3-year rotations of tobacco, wheat, and red clover, and corn, wheat, and red clover produced relatively poor yields of all the crops. In a 4-year rotation of tobacco, wheat, clover, and grass, better yields and slightly better quality of dark tobacco was produced than in a 4-year rotation of tobacco, soybeans, wheat, and red clover, with a crimson clover and rye cover crop following the tobacco.

On Berks silt loam at Staunton, a 5-year rotation of corn, wheat, wheat, clover and grass 2 years was the most suitable for corn production on hilly land with a net return per acre per year of \$13.30. A 4-year rotation of corn, wheat, clover and grass 2 years was most suitable for clover and grass hay production on rolling or level land. This rotation was the most profitable of the group studied (\$17.45). A 3-year rotation of corn, wheat, and sweetclover was best suited for wheat production and grazing (sweetclover) on level land (\$16.98). The other rotations used in this experiment were corn, wheat, and red clover (\$16.68); and corn, soybeans, wheat, clover and grass (\$12.64).

On Washington silt loam at Glade Spring a 3-year rotation of corn, wheat, clover and timothy (\$31.96) was the most profitable of the rotations tested, but the 3-year rotation of corn, barley, clover and timothy rates second in the net returns per acre per year (\$27.86).

Hutcheson states that for livestock production in southwest Virginia the 3-year rotations of corn, wheat, clover and timothy, and corn, barley, clover and timothy are well suited to the soil from the standpoint of ground cover, maintenance of soil fertility, and all-round usefulness. In 5- and 6-year rotations with corn, alfalfa has been a relatively low yielder of poor-quality hay, and the corn-alfalfa rotations have brought relatively small profits.

Other rotations used were corn, clover and timothy 2 years (3-year rotation), \$15.37; corn, wheat, clover and timothy 2 years (4-year rotation), \$22.64; corn, wheat, clover and timothy 2 years and timothy (5-year rotation), \$20.03; corn and sweetclover (2-year rotation), \$17.43; corn, wheat, wheat, clover and timothy 2 years (5-year rotation), \$19.45; corn, corn, alfalfa and timothy 4 years (6-year rotation), \$19.84; corn, alfalfa and timothy 4 years (5-year rotation), \$9.94.

Bondurant (13) reports that the limestone hill-land farms of the intermediate bluegrass area of central Kentucky are well adapted to the production of grass for livestock and most crops grown in the North Central States, especially burley tobacco and lespedeza.

³ Unpublished data obtained from T. B. Hutcheson, Virginia Agricultural Experiment Station, Blacksburg, Va.

The study reveals that the most profitable use of the land is with one-tenth or less of the arable land in cultivated crops, one-half to two-thirds of the land in pasture, and alfalfa on approximately one-sixth of the acreage. The most suitable rotation was (1) corn or tobacco; (2) wheat or rye; (3) legume and grass mixture for 8 to 10 years (first half of period for hay, last half for pasture).

Bailey, Williamson, and Duggar (6), in reporting on experiments with legumes in Alabama, point out the effectiveness of kudzu in yields of crops in subsequent years. The kudzu was planted in 1916 in the early spring, made very little growth that year but covered the ground in 1917, and made a heavy growth in 1918. It was plowed in the spring of 1919, and from 1919 to 1929, 13 crops were grown, consisting of 2 crops of sorghum hay, 4 of corn, and 7 of oats. The average yields of the crops are shown in table 16.

TABLE 16.—*Influence of kudzu on the yields of succeeding crops*

Plot Number	Growth of kudzu	Average yields of following crops		
		2 crops sorghum hay per acre	4 crops corn per acre	7 crops oats per acre
1	No kudzu.....	<i>Pounds</i> 3,264	<i>Bushels</i> 14.7	<i>Bushels</i> 16.6
2	Kudzu.....	5,800	34.0	24.5

Data from Alabama Agricultural Experiment Station Bull. 232, table 8, p. 21.

The data in the preceding table show that the residue from kudzu produced an average increase of 2,536 pounds of sorghum hay per acre in 1919 and 1920. The average yield of four crops of corn following kudzu was more than double the yield on the plot that had not grown kudzu. The average yield of seven crops of oats on the kudzu plot was 7.9 bushels per acre more than that on the plot that had grown no kudzu. In 1929, 10 years after the kudzu was turned under, the kudzu plot produced 9.2 bushels of oats per acre more than the plot on which kudzu had never grown.

The Georgia Coastal Plain Experiment Station (43, p. 100) points out some advantages in nematode control from the use of crop rotation. Three-year rotations (bright tobacco following 2 successive years of common field crops, and another after 2 years continuous fallow) have shown peanuts fairly effective in controlling nematodes in tobacco, and more effective than fallow (fig. 8).

The report reveals that longer rotations are generally more effective in reducing nematode damage than 2-year rotations, especially when weeds have been used in the 2-year rotation, but where peanuts or crotalaria have been used, the tobacco has been seriously damaged from root knot. Four-year rotations have been the most effective: Cotton, corn, harvested peanuts, and tobacco, grown in that order, give promise in nematode control.

Letteer (71) reports that, as a rule, root rot in Texas is much less serious where cotton is grown in rotation than continuously. In a rotation of oats, cotton, and milo, the number of dead cotton plants



COURTESY BUREAU PLANT INDUSTRY

FIGURE 8.—Crop rotation in the control of root knot in tobacco: The tobacco on the left was planted following two successive crops of sweetpotatoes; the tobacco on the right follows two successive crops of root knot-resistant weeds.

has been very small each year, whereas root-rot infestation on a nearby plot cropped continuously to cotton averaged 57 percent for 3 years (fig. 9).



FIGURE 9.—Successful seeding of little bluestem in the Texas blacklands. The contour sod strips were seeded in April 1936, and the picture was taken the following August.

ROTATIONS ON THE CONTOUR

As mentioned previously, practically all experiments on crop rotations conducted by experiment stations have been on level or gently sloping land, and the results can scarcely be applied to sloping lands



FIGURE 10.—Contour strip cropping on terraced land in Wisconsin. A definite rotation is followed. Left to right, the crops are grain, hay, corn, hay. Figure 11 shows the crops the following year.



FIGURE 11.—Rotation of crops in contour strip cropping in Wisconsin. Left to right, the crops are grain, corn, hay, grain, hay, potatoes. Figure 10 shows the crops the preceding year. It often takes 3 or 4 years to get the rotation established.

subject to erosion. Rotations are even more essential on sloping land than on level land. If they are to be truly effective in maintaining soil organic matter on sloping land, however, other measures must be employed to reduce soil and water losses, if such land must remain in cultivation (figs. 10 and 11).

Contour cultivation, terracing, and contour strip cropping are necessary adjuncts to crop rotations on sloping land, employed singly or in combination, as the erodibility of the soil demands. Contour strip cropping is discussed by Kell and Brown (66), who have pointed out that the flexibility of a strip-cropping system makes it possible to meet practically any crop- or livestock-production problems through proper arrangement of strips. Permanent close-growing strips of legumes, legume-grass mixture, or grass can be used in an arrangement that will allow a regular rotation of tilled crops, small grain, and legumes by fields. This arrangement meets the requirements of

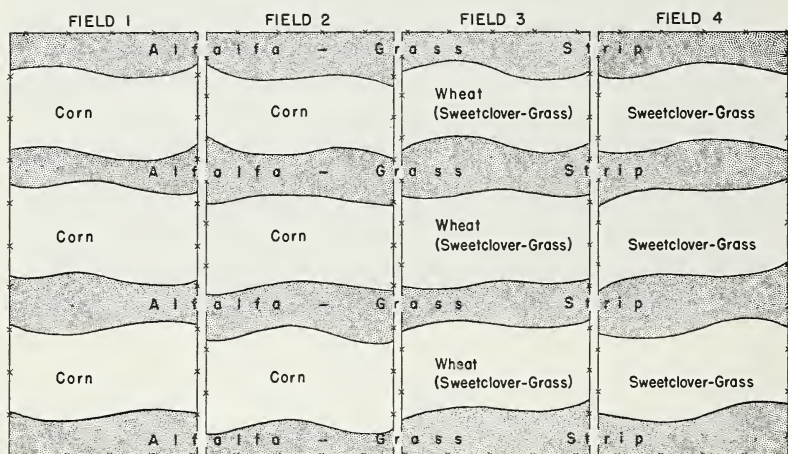


FIGURE 12.—Contour strip cropping that follows a definite crop rotation by fields, an arrangement that allows the livestock farmer to graze specific crops or to provide grazing during certain seasons of the year without constructing temporary fences. With fields 1 and 2 in corn, the alfalfa-grass strips can be cut for hay. Field 3 can be grazed after the wheat is removed and one hay crop is cut. Field 4 can be grazed throughout the summer.

the livestock farmer who finds it necessary to graze stubblefields, hay aftermath, or tilled crops after the harvest or who desires entire fields for grazing for a season, as in the case of a rotation of corn, small grain, and sweetclover. The permanent strips can be used for hay or for grazing, depending on the crop that is planted in the field at the time. All irregularities that occur in most fields and interfere with contour cultivation by necessitating point rows can be placed in the permanent strips of grass.

Such an arrangement (fig. 12) has other advantages in addition to its effectiveness in erosion control. Small grain can be harvested from contour strips without destroying any grain, since the binder or combine can make the initial round with the tractor or horses on the grass strip. The corn binder can be operated similarly, and the corn fodder can be shocked on the grass strip to prevent interference with preparing a seedbed and seeding winter wheat. The grass strips

can be plowed up after a few years and relocated. Following such a practice will in time put all the land in grass or grass-legume sod for a period of years, which is essential in maintaining soil organic matter and structure that will resist erosion.

GRASS-LEGUME MIXTURES

Roberts (106), in discussing soil-management problems in Kentucky, points out that legumes in mixture with pasture grasses are as important as in rotation with nonleguminous crops. Bluegrass was sown in 1923 on very good land at Lexington, one area with white clover and another without legumes. With the legume, the bluegrass yielded 2,400 pounds per acre; and where seeded alone, 870 pounds. Later cuttings indicated yields in approximately the same proportion, and analysis of the grass while at grazing stage gave 33 and 44 percent more protein in the grass-legume mixture for 2 different years.

In showing the value of the grass-legume mixture in soil improvement at the end of 8 years, Roberts analyzed the soil to a depth of 18 inches and found an increase of 62 pounds of nitrogen per acre under the grass and 406 pounds under the grass-legume mixture, in addition to the nitrogen removed in harvesting, which was practically four times as much in the grass-legume mixture as in the grass alone.

Roberts (107), in further discussion of legumes in cropping systems in Kentucky, reports on the effectiveness of grass-legume mixtures in preventing soil nitrogen losses.

Approximately 2 tons of Korean lespedeza per acre were incorporated into duplicate plots on the experiment station. Analyses were then made from time to time to determine the movement of soluble nitrate nitrogen in the soil. The average amounts of soluble (nitrate) nitrogen in pounds per acre at specified dates are given in table 17. No cover crop was seeded on these plots.

TABLE 17.—*The average amounts (parts per million) of soluble (nitrate) nitrogen in the soil at subsequent dates following the incorporation of 2 tons of Korean lespedeza in September (Kentucky)*

Depth (Inches)	Nov. 30	Jan. 7	Mar. 4	Apr. 10
0-6	16.4	25.4	9.7	4.7
6-18	11.4	21.8	19.3	6.1
18-30			20.0	8.3
30-42				6.1
42-54 (rock)				3.3
Totals	27.8	47.2	49.0	28.5

Data from Kentucky Agricultural Experiment Station Bull. 374, p. 143.

The record of precipitation during the period covered in the table is as follows (107, p. 144):

October, 0.68 inches; November, 3.41; December, 2.51; January, 5.11; February, 1.87; and March, 7.52 inches. Precipitation was less than normal except during January and March, and hence leaching probably was less than during an average year.

On other plots in this same experiment, rye was seeded as a cover crop after the lespedeza was incorporated. The rye prevented the

loss of nitrogen, since no loss was found after November 30, and very little at any time. From other studies the following data show the importance of various cover crops in conserving nitrogen:

	<i>Loss of nitrogen Oct. 10, 1933, to Mar. 31, 1936 Pounds per acre</i>
No vegetation.....	310
Bluegrass.....	17
Alfalfa.....	15
Alfalfa and bluegrass.....	7
Korean lespedeza and bluegrass.....	86

Roberts points out that the mixture of Korean lespedeza and bluegrass was practically all lespedeza, and that with more grass very little leaching would occur.

He gives additional data that indicate the effectiveness of legume-grass mixtures in increasing production with grass alone. The yields given are on the basis of cured hay with 10-percent moisture.

	<i>Pounds per acre</i>
1. Bluegrass alone (average 1930-34).....	1, 945
2. Bluegrass from plots on which legumes were associated with bluegrass but had disappeared before the harvest of bluegrass crops used in this average (average 1930-34).....	2, 950
3. Bluegrass alone (average 1929-35).....	1, 977
4. Bluegrass with which red clover, white clover, sweetclover, lespedeza, and alfalfa were seeded in the beginning, but from which the legumes wholly or partly disappeared. Legumes except red clover, and sweetclover included in harvest with grass until disappearance (average 1929-35).....	3, 580

In summarizing the studies described above, Roberts shows that in order to maintain good ground cover and prevent soil erosion, an abundant supply of nitrogen is necessary. With plenty of hay and pasture, less corn is needed for livestock feed and more land can be protected from erosion and leaching by a good sod cover. In the central bluegrass section of Kentucky, the production of grass is essential for the livestock industry and also important in tobacco production. Roberts makes it clear that the production of legumes to supply nitrogen for grass and other nonleguminous crops is dependent on the use of mineral supplements, particularly lime and phosphorus, not only for quantity production but also for the production of high-quality feed with sufficient minerals to nourish farm animals and human beings. He recognizes the need for proper land use and recommends keeping as much as possible of the steep land in pasture and hay, supplying sufficient treatment to get good growth. The grass should always have legumes in mixture. The production of grain crops should be confined, if possible, to the more level lands (fig. 13).

Willard, Thatcher, and Cutler (145) point out the many advantages of alfalfa-grass mixture seedings over alfalfa alone. Timothy, smooth brome grass, orchard grass, and other grasses can be successfully used, although timothy is preferred in Ohio. The use of timothy with alfalfa has made it possible to extend the use of the latter on heavy, poorly drained soil, where it cannot be seeded alone successfully because of excessive soil heaving.

Several of the State experiment stations in States where alfalfa is adapted are encouraging the use of alfalfa-grass mixtures as a result of experimental plantings. There are soils on which alfalfa seeded alone actually increases the erosion hazard, such as the loessial soils in eastern Nebraska, where numerous fields in alfalfa have caved in at several points, owing no doubt to water's following the openings made by the alfalfa roots. The addition of grass to the seeding prevents the development of such depressions.

The importance of clover-grass mixtures has long been recognized (fig. 14), and throughout the Northeastern States and the Corn Belt, seedings of red clover are invariably made with timothy in mixture. Seeding grass with sweetclover, however, has not been a general practice, and it needs further investigation. This legume plays a very



FIGURE 13.—Steep slopes can be successfully farmed if kept for half or more of the time in perennial legumes and grasses. This slope in Whitman County, Wash., is seeded to an alfalfa-grass mixture.

important role in farm economy in several sections of the country. It has been noted in some localities in the Great Plains that sweetclover often leaves the soil so loose that it blows readily. Rapid-growing winter annual or short-lived perennial grasses seeded with sweetclover, where adapted, offer promising possibilities of preventing this soil condition.

The use of legume-grass mixtures instead of grass or legumes offers a solution to problems frequently encountered with subsequent crops. As already pointed out, grasses frequently depress yields of subsequent crops because they incorporate too much cellulose, which reduces available nitrates. Legumes frequently overstimulate the vegetative growth of the following crop, particularly on soils of low organic content, and as a result the crop is very susceptible to periods

of drought and hot winds, which ordinarily would not damage the same crop grown following grass or a grass-legume mixture. The stimulation is produced by an abundance of nitrates. The effect is much less noticeable on soils well supplied with organic matter, since these soils generally contain a better balance of plant food and more moisture, which is usually available through a longer period.

An interest in a permanent agriculture accords with a general policy of using grass-legume mixtures on sloping lands subject to erosion, whether in cropland or permanent pasture, instead of seedings of grass or legumes singly. Exceptions are necessary, naturally, where adapted grasses or legumes are not available.



FIGURE 14.—The change from soil loss to soil building on this formerly gullied area in Washington came with the seeding of alsike clover, brome grass, meadow fescue, and redtop seeded in mixture.

ROTATIONS RECOMMENDED FOR ERODIBLE SOILS

In examining the principal crop-production areas in the United States and the type-of-farming practices, it seems apparent that there is a close correlation between erosion problems and lack of adequate crop rotation. The sections of the country with most severe and uncontrolled erosion are those of continuous cash crops. Erosion is most serious in the Southeastern States, where continuous cotton production has been the general rule. Detailed examination within erosion-problem areas reveals that those farms confined strictly to one-crop production show the most striking erosion. Under the one-crop system, usually the farm that has received the most intense cultivation is most severely eroded.

Considering rotations in relation to erosion control and attempting at the same time to give full consideration to the economic aspects

of the farm business bring up very serious problems. It has been necessary, owing to the extensive program under way, to develop standard recommendations for erosion control, based on soil type, slope, and degree of erosion. Under certain conditions of soil, slope, and erosion, it is advisable to retire the land to grass or perhaps to trees. There are many farms in such condition that all the land should be retired to permanent cover merely to check erosion. If this is done, how are the farmers to live? Rotations for soil protection and improvement are generally of necessity long, with 2 or more consecutive years in sod. Installation of long rotations also tends to cut the acreage of cash crops.

It is not the intent to discuss methods of meeting the situation except so far as crop rotations apply. It appears that, regardless of the supplemental practices used, erosion cannot be controlled, but merely retarded, unless adequate rotations are provided. It is only when proper cropping practices that reduce erosion to a minimum are employed that a truly permanent agriculture is effected. In many instances, such supplemental practices as contour farming, terracing, and strip cropping, and the provision of proper mineral supplements, are essential in addition to a sound crop rotation if erosion is to be checked and a permanent cropping program assured.

The Iowa Agricultural Experiment Station and Extension Service, in cooperation with the Soil Conservation Service, have developed standard recommendations for erosion control that may be applied under the numerous conditions of soil, slope, and degree of erosion that occur in the State. The plan, although developed for 250 soil types, 6 slope classifications, and 4 degree-of-erosion classes, is comparatively simple in application. Simplification has been made possible by placing all the soil types in 5 groups, using the potential productive power for corn, small grains, and legume crops as a basis for the grouping. The ratings place the best soils in group 1, the poorest in group 5, and the intermediate soils in the intervening groups. Optional ratings are necessary with many of the soils because of drainage conditions. The degree-of-erosion classes used are (1) slight to none, (2) moderate, (3) serious, and (4) severe. In the first class less than 25 percent of the surface soil has been removed, in the second 25 to 50 percent, in the third 50 to 75 percent, and in the fourth 75 percent or more. All the commonly grown crops have been used in developing the recommended rotations. These rotations have been built up from available information combined with the judgment of a group of men with many years' first-hand experience with the soils, crops, and erosion problems of Iowa farms.

Data concerning slope and erosion must also be available. These data can be obtained by soil technicians in connection with the regular soil survey or by a separate survey if a soil survey of the area that does not include data on slope and erosion has already been made. The information is fundamental to proper application of the plan.

Table 18 summarizes the recommendations concerning cropping, and extends from short to long rotations. Permanent pasture is included for those areas not safe to crop. The symbols, consisting of numbers and letters, given in the table, refer to the cropping recommendations listed at the end of the table. Legends are also given at the end of the table for specific crops. Soil types within groupings

TABLE 18.—Suggested crop rotations for Iowa, according to soil group, degrees of sheet erosion, and land slope

Soil group	Degree of erosion	Slope 0-3 percent	Slope 3-6 percent	Slope 6-10 percent	Slope 10-15 percent	Slope 15-20 percent	Slope 20 percent and over
1	(Slight to none)	1, 5a, 5b, 5c, 6, 12a, 12b, 11b, 11c, 13.	1, 2, 3, 5a, 5c, 5d, 6, 9, 11c, 12a, 12b.	2, 3, 4a, 5d, 11a, 12b	2, 4a, 4b, 4c, 5d, 7, 10, 11a.	2, 4a, 4b, 4c, 5d, 7, 10, 11a.	7
	(Moderate)	1, 3, 5a, 5c, 6, 9, 11b, 11c, 12a, 12b, 13.	1, 2, 3, 5a, 5c, 5d, 9, 11c, 12a, 12b.	2, 4a, 4b, 5d, 10, 11a	2, 4a, 4b, 4c, 5d, 10, 11a	2, 4a, 4b, 4c, 5d, 10, 11a, 7	7
	(Serious)		2, 4a, 4b, 4c, 5d, 10, 11a	2, 4a, 4b, 4c, 5d, 7, 10, 11a	2, 4a, 4b, 4c, 5d, 7, 10, 11a	7	7
2	(Slight to none)	1, 3, 5a, 5b, 5c, 5d, 6, 9, 11c, 12a, 12b, 13.	1, 2, 3, 5a, 5c, 5d, 6, 9, 11c, 12a, 12b.	2, 3, 4a, 5d, 10, 11a, 12b.	2, 4a, 4b, 4c, 5d, 10, 11a	2, 4a, 4b, 4c, 5d, 7, 10, 11a	7
	(Moderate)	1, 3, 5a, 5c, 6, 9, 11b, 11c, 12a, 12b.	2, 3, 5d, 9, 10, 11c, 12b.	2, 4a, 4b, 5d, 10, 11a	2, 4a, 4b, 4c, 5d, 7, 10, 11a	2, 4a, 4b, 4c, 5d, 7, 12, 11a	7
	(Serious)		2, 4a, 4b, 4c, 5d, 10, 11a	4b, 4c, 7, 10	4c, 7, 10	7	7
3	(Slight to none)	2, 4a, 4b, 4c, 5d, 8, 10, 11a	2, 4a, 4b, 4c, 5d, 8, 10, 11a	4b, 4c, 7, 10	4b, 4c, 7, 10	7	7
	(Moderate)	2, 4a, 4b, 4c, 5d, 8, 10, 11a	4a, 4b, 4c, 5d, 7, 11a	4b, 4c, 7	4b, 4c, 7	7	7
	(Serious)	4a, 4b, 4c, 7, 11a	4b, 4c, 7	7	7	7	7
4	(Slight to none)	2, 4a, 4b, 4c, 5d, 7, 8, 11a	4a, 4b, 4c, 7, 11a	4b, 4c, 7	4b, 4c, 7	7	7
	(Moderate)	4a, 4b, 4c, 7, 8, 11a	4a, 4b, 4c, 7, 11a	4b, 4c, 7	4b, 4c, 7	7	7
	(Serious)	4b, 4c, 7	4b, 4c, 7	7	7	7	7
5	(Slight to none)	4a, 4b, 4c, 7, 8, 11a	4b, 4c, 7, 8	4b, 4c, 7	4b, 4c, 7	7	7
	(Moderate)	4a, 4b, 4c, 7, 8, 11a	4b, 4c, 7	4b, 4c, 7	4b, 4c, 7	7	7
	(Serious)	4b, 4c, 7	4c, 7	7	7	7	7
	(Slight to none)						
	(Moderate)						
	(Serious)						

Degrees of sheet erosion:

- (1) Slight to none: Less than 25 percent of the surface soil washed away.
- (2) Moderate: From 25 to 50 percent of surface soil washed away.
- (3) Serious: From 50 to 75 percent of surface soil washed away.
- (4) Severe: Seventy-five percent or over of surface soil washed away.

ROTATIONS

- 1—C-C-SG-LH.
 2—C-C-SG-LH.
 3—C-C-SG-MH-RP.
 4 (a) C-C-SG-MH-RP.
 (b) C-SG-MH-RP-RP.
 (c) C-SG-MH-RP-RP.
 5 (a) C-C-SG-Swel (4 years).
 (b) C-C-SG-Swel (3 years).
 (c) C-C-SG-Swel (2 years).
 (d) C-C-SG-Swel (3 years).

LEGEND

- 6—C-C-SG-WW-LH.
 7—Permanent pasture.
 8—Special crops.
 9—C-SB-WW-MH-RP-RP.
 10—C-SG-WW-MH-RP.
 11 (a) C-SG-Alf. (2).
 (b) C-SB-SG-LH.
 (c) C-SB-WW-LH.
 12 (a) C-C-SG-WW-Alf. (3).
 (b) C-C-SG-Alf. (3).
 13—C-SB-C-SG-LH.
- Swel—Sweetclover.
 C—Corn.
 SG—Small grain.
 MH—Mixed hay.
 RP—Rotation pasture.
 WW—Winter wheat.
 SB—Soybeans.
 LH—Legume hay.
 Alf—Alfalfa.

are not given here but these can be obtained from the original publication,⁴ from which table 18 has been taken.

It will become evident immediately that in any particular locality this table of crop rotations is limited in use since it gives only a few soil types, although these may represent all five soil groups. Grouping the soils according to productivity is the most difficult and important step in developing the plan, and when this has been done it is a simple task to develop the necessary data for a small drainage area, a township, or even a county.

It will be noted that supporting practices are shown in table 19. It is possible to use contour cultivation, contour strip cropping, and terracing, where adapted to local conditions, and to reduce the rigidity of the rotation. For example, on group 1 soil, from 2 to 7 percent slope, with moderate erosion, strip cropping or terracing allows 33 percent of the land in cultivated crops, whereas without strip cropping or terracing only 25 percent of the land is placed in cultivated crops. On the same soil and slope with serious erosion, terracing allows 25 percent in cultivated crops, and strip cropping or contour cultivation 20 percent, whereas without supporting practices, only 16 percent is allowable.

Boatman⁵ discusses the general plan of applying crop rotations to effect conservation of the soil in the upper Mississippi Valley and emphasizes the necessity of giving consideration to the physical characteristics of the soil and the degree of erosion in addition to several other factors. Boatman has been active in developing the general plan of approach to crop-rotation problems given in the two preceding tables and in the table on page 40.

Cardon⁶ says: * * * the ideal of soil conservation in America will become a fact when farm practice generally accepts and includes in cropping systems grass as grass and not as an expedient. When American farmers become truly grass conscious, they will plant and manage grass in rotation with other crops because they appreciate its intrinsic values. Then, soil conservation, in all its aspects, will follow as a natural consequence. * * * Farmers will accord grass its proper place in American agriculture when they become convinced that grass culture is economically feasible not only as a dependable source of feed for livestock, but as a soil-improving crop to be reflected in the returns from other crops and as an otherwise legitimate component of cropping enterprises.

The main value of crop rotation for erosion control lies in the sod crop and the reduction in soil cultivation or tillage. As has been pointed out clearly by Bradfield (14), sod crops, and grass in particular, produce an excellent physical condition of the soil, and this is essential in erosion control. Many of our soils have been seriously abused; in addition to severe damage by erosion, the organic content is very low. To restore organic matter and to recondition soils physically it is necessary to return them to sod. The poorer the soil in organic matter and the more susceptible it is to erosion, the greater the percentage of the time it should be kept under sod, if it is to be improved or even maintained. In addition, the years in sod should be consecutive. Two consecutive years of sod crops in the rotation, followed by 2

⁴IOWA AGRICULTURAL EXPERIMENT STATION, IOWA AGRICULTURAL EXTENSION SERVICE, and UNITED STATES SOIL CONSERVATION SERVICE. SUGGESTED CROP ROTATIONS ACCORDING TO SOIL GROUPS, DEGREES OF SHEET EROSION AND LAND SLOPES. [6] pp., illus. n. d. [Mimeographed.]

⁵BOATMAN, J. L. CROP ROTATIONS AND STRIP CROPPING FOR EROSION CONTROL IN THE UPPER MISSISSIPPI VALLEY. Paper presented at the annual meeting of the Amer. Soc. Agron. Nov. 16-18, 1938. 5 pp. 1938. [Mimeographed.]

⁶CARDON, P. V. THE PLACE OF GRASS IN AN EROSION-CONTROL PROGRAM. Paper presented at annual meeting Amer. Soc. Agron. Nov. 16-18, 1938. 5 pp. [Mimeographed.]

TABLE 19.—*Recommended land use, crop rotations, and supporting conservation practices based on soil type, slope, and degree of erosion. Lime and fertilizer are to be applied according to test or need*

Soil type	Slope	Degree of erosion															
		Slight (1-2)				Moderate (3)				Serious (33)				Severe (4)			
		N	C	S	T	N	C	S	T	N	C	S	T	N	C	S	T
I Grundy	A, 0-2%	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Tama	B, 2-7%	3	3	2	2	4	4	3	3	6	5	5	4	x	x	x	x
Muscatine	BB, 7-12%	x	x	x	x	6	5	5	4	8	6	5	x	x	x	x	x
II Clinton	A, 0-2%	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Shelby	B, 2-7%	5	5	4	4	6	5	4	4	8	7	6	5	8	7	x	6
	BB, 7-12%	x	x	x	x	8	6	5	5	8	6	6	9	9	9	9	9
	C, 12-15%	x	x	x	x	9	8	9	9	9	9	9	9	9	9	9	9
	D, 15%	x	x	x	x	9	9	9	9	9	9	9	9	9	9	9	9
III Gosport	A, 0-2%	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Lindley	B, 2-7%	x	x	x	x	9	9	9	9	9	9	9	9	9	9	9	9
	BB, 7-12%	x	x	x	x	9	9	9	9	9	9	9	9	9	9	9	9
	C, 12-15%	x	x	x	x	9	9	9	9	9	9	9	9	9	9	9	9
	D, 15%	x	x	x	x	9	9	9	9	9	9	9	9	9	9	9	9

Recommended practice. N=No practices. C=Contour tillage. S=Strip cropping. T=Terracing.
x=No such condition exists.

[Percentage tilled crop]

	Percent		Percent
1. C-C-SG-Me	50	6. C-SG-Me-Me-Me-Me	16
2. C-C-SG-Me-Me	40	7. SG-Me (4 yrs.)	0
3. C-SG-Me	33	8. Permanent hay	0
4. C-SG-Me-Me	25	9. Permanent pasture	0
5. C-SG-Me-Me-Me	20	10. Woodland	0

years' cultivation, is a much more desirable arrangement than alternation annually of sod and cultivated crops. One year's production of roots by a sod crop can accomplish little toward soil improvement, even under favorable soil and moisture conditions. With moderate to serious erosion present, even on a moderate slope, 2 consecutive years in sod is essential, and as the slope and erosion increase, years in sod must increase until a point is reached at which the land cannot be farmed to tilled crops but must be kept in sod crops permanently.

For the prevention of erosion damage, the selection of the particular crop grown in the rotation is generally not important. The cultivated crop may be corn, cotton, potatoes, or any other row crop; the small grain may be wheat, barley, oats, or rye, although spring or fall planting may make a considerable difference in the amount of erosion; and the sod crop may be one or more of innumerable grasses or grasses and legumes. The principal importance of the rotation in erosion control lies in the number of years in each of these three groups of crops; there being little if any advantage in rotating corn and cotton, or corn, small grain, and cotton on erodible soils. Millions of acres of land have been lost under these and similar rotations. It must be recognized that the time spent under sod is the soil-rebuilding period. And sod alone will not suffice, unless the necessary mineral supplements, such as lime, phosphate, and potash, are provided. Even grass will not grow without plant nutrients; and without heavy root formation, the soil will not be improved. Further, it cannot be expected that soil will be improved if the sod crop is closely and continuously harvested. In order to develop good root systems, grasses and legumes must be allowed to make substantial top growth.

The crop rotation alone is not capable of controlling erosion, but it is fundamental to erosion control and permanent agriculture. It

has been seriously neglected, and must now be given its place. The introduction to the farms of this country of crop rotations that are adequate for erosion control, when these rotations are supplemented by supporting practices, fertilizers, manure, and good farm management, will aid very materially in stabilizing crop production and in developing a sound and permanent agriculture.

SUMMARY AND CONCLUSIONS

In the literature dealing with crop rotations there is a dearth of information applicable to erodible soils. The need for additional experimental work with crop sequence and rotation in order to make plans and recommendations for preventing soil losses is extremely urgent.

Considerable information is presented that shows tremendous losses in soil organic matter occur under continuous production of a single small-grain or row crop on soils subject to little or no erosion. Soil organic matter has not been maintained under crop rotation, although the losses have been materially reduced where land has been kept in sod crops for 2 or more consecutive years. Increases are reported under continuous grass and continuous alfalfa on lands subject to little or no erosion.

Soil organic matter is important in preventing both wind and water erosion. The granular structure produced by grass roots in prairie soils is highly resistant to wind and water erosion, whereas sweet-clover frequently leaves the soil loose and particularly subject to wind erosion under semiarid conditions. The erosion-control value of different kinds of organic matter, whether it be produced by various species of plants, or supplied as manure or mulch, needs much study, since it is apparent that results vary on different soils and under different climatic conditions.

The sequence of crops in the rotation is highly important, as is indicated by the limited information available. Crop sequence is effective not only in amending crop yields and soil erosion, but in the control of plant diseases and insects. Studies of crop sequences and their effect on erosion control are greatly needed.

An attempt to develop recommendations for erosion control from a review of the literature results in a somewhat confused picture, or even in conflicting recommendations. This merely emphasizes the need for carefully planned experimental work designed to determine the type of farming that can be conducted under the many varied physical conditions in order to develop a truly permanent agriculture. Presentation of pertinent information for the great soil groups has been attempted.

In the northern Great Plains, sod crops apparently are an essential part of the rotation, grass rather than legumes being used as the basis of sod in dry-land farming. Alfalfa can serve effectively as a sod crop under irrigation. For erodible soils, grass-legume mixtures should be used where sufficient moisture is available to produce legumes. The use of legumes for green manure in dry-land farming shows no advantage. Information is needed concerning the length of the rotation and the period the land should remain in sod. More information is needed on the use of crop residues, trashy fallow, grass establishment, and many other problems relating to crop rotation.

The use of legumes in the crop rotation is a generally accepted practice in the Corn Belt. It is recognized that grass-legume mixtures are essential in rotations for erodible soils, and that as the susceptibility to erosion increases the number of consecutive years of sod in the rotation should increase or the years of cultivated crop should decrease. The importance of lime and phosphate in increasing or maintaining the organic matter cannot be overemphasized. More experimental work comparing the comparative effectiveness of acid-tolerant and lime-loving legumes in a permanent agriculture, is needed.

From the standpoint of the soil conservationist, the crop rotations of the Northeastern States are more nearly representative of rotations in a truly permanent agriculture than those of any other section of the country. Several grasses are well adapted, easily established, and widely used. The need of lime and phosphate, even where these amendments are extensively used, as in the Corn Belt, deserves more emphasis.

In the improvement of physical conditions of the soil, the urgent need in the Southeastern States is for perennial grasses and legumes that can be readily established and used in the crop rotation. In general, the soils are more nearly depleted of organic matter and more severely eroded than in any other section of the country. Little use has been made of lime, but the need for it and for phosphate in any attempt to rebuild the supply of organic matter is urgent.

Crop rotations must be considered first in relation to the physical aspects of land use if a permanent agriculture is to be maintained. The natural fertility of the soil, its present condition, the slope, and the climate are all extremely important in any program of proper land use. With full consideration given to these and to supporting engineering practices, field arrangements, and proper mineral supplements, the time has come for the attempt to establish the cropping practices to meet the economic requirements of production.

BIBLIOGRAPHY

- (1) ALBRECHT, WILLIAM A.
1938. LOSS OF SOIL ORGANIC MATTER AND ITS RESTORATION. Soils and Men (U. S. Dept. Agr. Yearbook 1938): 347-360, illus.
- (2) AMERICAN SOCIETY OF AGRONOMY.
1938. MINUTES OF THE THIRTY-FIRST ANNUAL MEETING OF THE SOCIETY. Amer. Soc. Agron. Jour. 30: 1049-1072.
- (3) ARNY, A. C.
1917. CROP ROTATION INVESTIGATIONS. FIELD T. EXPERIMENTS. Minn. Agr. Expt. Sta. Bul. 170, 55 pp., illus.
- (4) ATKINSON, ALFRED, and WILSON, M. L.
1915. CORN IN MONTANA. Mont. Agr. Expt. Sta. Bul. 107, pp. [14]-[128], illus.
- (5) BACHTELL, MYRON A., and ALLEN, HAROLD.
1934. ALFALFA-TIMOTHY HAY FOR THE DAIRY FARM. PART I—GROWING HIGH-GRADE HAY IN LIBERAL AMOUNTS. Ohio Agr. Expt. Sta. Bul. 538; 1-20, illus.
- (6) BAILEY, R. Y., WILLIAMSON, J. T., and DUGGAR, J. F.
1930. EXPERIMENTS WITH LEGUMES IN ALABAMA. Ala. Agr. Expt. Sta. Bul. 232, 45 pp., illus.
- (7) BALDWIN, MARK; KELLOGG, CHARLES E.; and THORP, JAMES.
1938. SOIL CLASSIFICATION. Soils and Men (U. S. Dept. Agr. Yearbook 1938): 979-1001.

- (8) BAKER, G. ORIEN, and KLAGES, K. H. W.
1938. CROP ROTATION STUDIES. Idaho Agr. Expt. Sta. Bul. 227, 34 pp., illus.
- (9) BIZZELL, JAMES A., and MORGAN, J. OSCAR.
1908. THIRD REPORT ON THE INFLUENCE OF MANURES ON THE YIELD OF TIMOTHY HAY. N. Y. (Cornell) Agr. Expt. Sta. Bul. 261, pp. 259-276, illus.
- (10) BLAIR, E. C.
1931. CROP ROTATIONS FOR PIEDMONT NORTH CAROLINA. N. C. Agr. Col. Ext. Cir. 188, 10 pp., illus.
- (11) ———
1936. CROP ROTATIONS FOR THE COASTAL PLAIN OF NORTH CAROLINA. N. C. Agr. Col. Ext. Cir. 165, 15 pp., illus. (Revised.)
- (12) BLOODGATE, DEAN W., and CURRY, ALBERT S.
1925. NET REQUIREMENTS OF CROPS FOR IRRIGATION WATER IN THE MESILLA VALLEY, NEW MEXICO. N. Mex. Agr. Col. Ext. Bul. 149, 48 pp., illus.
- (13) BONDURANT, JOHN H.
1938. FACTORS FOR PROFITABLE FARMING ON LIMESTONE HILL LAND OF THE EDEN FORMATION IN KENTUCKY. Ky. Agr. Expt. Sta. Bul. 384, pp. 225-246, illus.
- (14) BRADFIELD, RICHARD.
1937. SOIL CONSERVATION FROM THE STANDPOINT OF SOIL PHYSICS. Amer. Soc. Agron. Jour. 29: 85-92.
- (15) BROWN, B. A.
1936. CONTINUOUS CULTURE VERSUS ROTATION FOR POTATOES. Amer. Potato Jour. 13: 313-315, illus.
- (16) ——— and MUNSELL, R. I.
1936. PASTURE INVESTIGATIONS (SEVENTH REPORT). SPECIES AND VARIETIES OF GRASSES AND LEGUMES FOR PASTURES. Conn. (Storrs) Agr. Expt. Sta. Bul. 208, 33 pp.
- (17) BROWN, D. E., and McMURTREY, J. E., JR.
1934. VALUE OF NATURAL WEED FALLOW IN THE CROPPING SYSTEM FOR TOBACCO. Md. Agr. Expt. Sta. Bull. 363, pp. 401-410, illus.
- (18) BROWN, P. E.
1936. SOILS OF IOWA. Iowa Agr. Expt. Sta. Spec. Rpt. 3, 261 pp., illus.
- (19) BROWNING, G. M.
1938. CHANGES IN THE ERODIBILITY OF SOILS BROUGHT ABOUT BY THE APPLICATION OF ORGANIC MATTER. Soil Sci. Soc. Amer. Proc. 1937: 85-96, illus.
- (20) BUIE, T. S., CURRIN, R. E., KYZER, E. D., and WARNER, J. D.
1929. FERTILIZER ROTATION EXPERIMENTS AT THE PEE DEE STATION. S. C. Agr. Expt. Sta. Bul. 262, 38 pp., illus.
- (21) ——— and WARNER, J. D.
1928. COTTON FERTILIZER EXPERIMENTS. S. C. Agr. Expt. Sta. Bul. 245, 32 pp., illus.
- (22) BURGESS, PAUL S.
1924. THE YIELD AND MINERAL CONTENT OF CROP PLANTS AS INFLUENCED BY THOSE PRECEDING. R. I. Agr. Expt. Sta. Bul. 198, 25 pp.
- (23) COLE, JOHN S.
1921. CROP ROTATION AND CULTURAL METHODS AT EDGELEY, N. DAK. U. S. Dept. Agr. Bul. 991, 24 pp., illus.
- (24) COLLIER, GEORGE W., and JOHNSON, O. R.
1938. EFFECTS OF BETTER SELECTION OF CROPS AND PASTURES ON FARM INCOME IN MISSOURI. Mo. Agr. Expt. Sta. Res. Bul. 282, 62 pp., illus.
- (25) COX, J. F., and MEGEE, C. R.
1924. THE CLOVERS AND CLOVER SEED PRODUCTION IN MICHIGAN. Mich. Agr. Expt. Sta. Spec. Bul. 130, 23 pp., illus.
- (26) COX, JOSEPH F.
1930. CROP PRODUCTION AND MANAGEMENT. Ed. 2, rev., 469 pp., illus. New York and London.
- (27) CRANDALL, F. K.
1937. THE RESPONSE OF CELERY TO MANURES AND FERTILIZER. R. I. Agr. Expt. Sta. Bul. 260, 22 pp., illus.

- (28) CRANDALL, F. K., and HARTWELL, BURT L.
1936. A COMPARISON OF FOUR LEGUMES AS REGARDS THEIR ABILITY TO WITHSTAND WINTER CONDITIONS AND INCREASE THE YIELDS OF THE TRUCK CROPS FOLLOWING. *Amer. Soc. Agron. Jour.* 17: 363-367.
- (29) ——— and ODLAND, T. E.
1930. THE AMOUNT OF MANURE NECESSARY FOR VEGETABLE GROWING. II. *R. I. Agr. Expt. Sta. Bul.* 225, 31 pp., illus.
- (30) ——— and ODLAND, T. E.
1932. SUBSTITUTING FERTILIZERS, GREEN MANURE, AND PEAT FOR STABLE MANURE IN THE GROWING OF VEGETABLES. *R. I. Agr. Expt. Sta. Bul.* 234, 53 pp., illus.
- (31) DAMON, S. C.
1919. A FIVE-YEAR ROTATION OF POTATOES, RYE STRAW AND SQUASHES, ONIONS, OATS AND ROWEN, AND HAY. *R. I. Agr. Expt. Sta. Bul.* 178, 15 pp., illus.
- (32) DAVIS, F. L., and LOVETT, H. C.
1937. SOIL FERTILITY AND FERTILIZER INVESTIGATIONS. *La. Agr. Expt. Sta. Bul.* 283: 42-47, illus.
- (33) DAVIS, KARY CADMUS.
1927. PRODUCTIVE PLANT HUSBANDRY . . . Ed. 4, enl., 462 pp., illus. Philadelphia and London.
- (34) DETURK, E. E.
1937. SOIL CONSERVATION FROM THE VIEWPOINT OF SOIL CHEMISTRY. *Amer. Soc. Agron. Jour.* 29: 93-112, illus.
- (35) DITTMER, HOWARD J.
1938. A QUANTITATIVE STUDY OF THE SUBTERRANEAN MEMBERS OF THREE FIELD GRASSES. *Amer. Jour. Bot.* 25: 654-657.
- (36) DODD, D. R., GARBER, R. J., and ODLAND, T. E.
1928. CROP ROTATIONS FOR WEST VIRGINIA. *W. Va. Agr. Expt. Sta. Cir.* 50, 23 pp., illus.
- (37) DOWN, E. E., and THAYER, J. W. JR.
1937. OAT CULTURE IN MICHIGAN. *Mich. Agr. Col. Ext. Bul.* 177, 14 pp., illus.
- (38) ETHERIDGE, W. C.
1938. LAND DECAY AND A PREVENTION. *Mo. Farmer* 30 (9):1.
- (39) ———
1938. SOIL CONSERVATION WITH GOOD CROPS. *Mo. Farmer* 30 (10):1.
- (40) ——— and HELM, C. A.
1936. KOREAN LESPEDEZA IN ROTATIONS OF CROPS AND PASTURES. *Mo. Agr. Expt. Sta. Bul.* 360, 22 pp., illus.
- (41) GAREY, L. F.
1937. SYSTEMS OF FARMING AND POSSIBLE ALTERNATIVES IN NEBRASKA. *Nebr. Agr. Expt. Sta. Bul.* 309, 50 pp., illus.
- (42) GEORGIA COASTAL PLAIN EXPERIMENT STATION.
1936. ESTABLISHING IMPROVED PASTURES IN THE COASTAL PLAIN OF GEORGIA. *Ga. Coastal Plain Expt. Sta. Cir.* 6, [14] pp., illus.
- (43) ———.
1936. SIXTEENTH ANNUAL REPORT 1935-1936. *Ga. Coastal Plain Expt. Sta. Bul.* 26, 106 pp., illus.
- (44) GILMORE, JOHN W., and CLARK, CHARLES F.
1906. SECOND REPORT OF THE INFLUENCE OF FERTILIZERS ON THE YIELD OF TIMOTHY HAY. *N. Y. (Cornell) Agr. Expt. Sta. Bul.* 241, 19 pp., illus.
- (45) GROSS, D. L., and DOLL, E. H.
1938. SOIL AND MOISTURE CONSERVATION IN NEBRASKA. *Nebr. Agr. Col. Ext. Cir.* 118, 31 pp., illus.
- (46) HADDON, C. B.
(n. d.) BIENNIAL REPORT OF THE NORTHEAST LOUISIANA EXPERIMENT STATION 1935-1936. 12 pp.
- (47) HARRIS, HENRY C., and PHILLIPS, C. E.
1933. ALFALFA PRODUCTION IN DELAWARE. *Del. Univ. Agr. Ext. Bul.* 18, 14 pp., illus.
- (48) HARTWELL, BURT L., and CRANDALL, F. K.
1922-28. THE SUBSTITUTION OF STABLE MANURE BY FERTILIZERS, GREEN MANURES, AND PEAT. I-III. *R. I. Agr. Expt. Sta. Buls.* 188, 201, and 216.

- (49) HARTWELL, BURT L., and CRANDALL, F. K.
1923. ON THE AMOUNT OF STABLE MANURE NECESSARY FOR VEGETABLE GROWING. R. I. Agr. Expt. Sta. Bul. 195, 16 pp.
- (50) ——— and DAMON, S. C.
1916. A TWENTY-YEAR COMPARISON OF DIFFERENT ROTATIONS OF CORN, POTATOES, RYE, AND GRASS. R. I. Agr. Expt. Sta. Bul. 167, 38 pp.
- (51) ——— and DAMON, S. C.
1918. THE INFLUENCE OF CROP PLANTS ON THOSE WHICH FOLLOW. I. R. I. Agr. Expt. Sta. Bul. 175, 30 pp., illus.
- (52) ——— and DAMON, S. C.
1920. FERTILIZER VERSUS MANURE FOR CONTINUOUS VEGETABLE GROWING. R. I. Agr. Expt. Sta. Bul. 182, 11 pp., illus.
- (53) ——— and DAMON, S. C.
1921. FERTILIZER REQUIREMENTS OF ROTATIONS, INCLUDING CORN, POTATOES, RYE, AND HAY. R. I. Agr. Expt. Sta. Bul. 185, 39 pp.
- (54) ——— PEMBER, F. R., and MERKLE, G. E. ✓
1919. THE INFLUENCE OF CROP PLANTS ON THOSE WHICH FOLLOW. II. R. I. Agr. Expt. Sta. Bul. 176, 47 pp., illus.
- (55) ——— SMITH, JOHN B., and DAMON, S. C. ✓
1927. THE INFLUENCE OF CROP PLANTS ON THOSE WHICH FOLLOW. III. R. I. Agr. Expt. Sta. Bul. 210, 23 pp.
- (56) HASTINGS, STEPHEN H.
1936. IRRIGATED CROP ROTATIONS IN WESTERN NEBRASKA, 1912-34. U. S. Dept. Agr. Tech. Bul. 512, 36 pp., illus.
- (57) HAWKINS, R. S.
1930. FIELD EXPERIMENTS WITH COTTON. Ariz. Agr. Expt. Sta. Bul. 135, pp. [553]-581, illus.
- (58) HAYS, W. M., BOSS, ANDREW, and WILSON, A. D.
1908. THE ROTATION OF CROPS. I. REPORT OF 10 YEARS ON 44 ROTATION CROPS. 2. INFLUENCE OF ROTATION OF CROPS AND CONTINUOUS CULTIVATION UPON THE FERTILITY AND COMPOSITION OF SOILS. Minn. Agr. Expt. Sta. Bul. 109, pp. [281]-358, illus.
- (59) HOLDER, T. D., and HUNTER, H. A.
1934. PRODUCING SNAP BEANS FOR CANNING. Md. Univ. [Agr.] Ext. Cir. 104, 11 pp., illus.
- (60) HOPKINS, CYRIL G.
1910. SOIL FERTILITY AND PERMANENT AGRICULTURE. 653 pp., illus. Boston, New York, [etc.].
- (61) HUGHES, H. D., and WILKINS, F. S.
1926. SUDAN GRASS. Iowa Agr. Expt. Sta. Bul. 233, pp. [125]-149, illus.
- (62) HUGHES, HAROLD D., and HENSON, EDWIN R.
1935. CROP PRODUCTION; PRINCIPLES AND PRACTICES; A HANDBOOK OF INFORMATION FOR THE STUDENT OF AGRICULTURE. 816 pp., illus. New York.
- (63) HUNTER, H. A., and HOLDER, T. D.
1933. TOMATO PRODUCTION FOR CANNING. Md. Univ. [Agr.] Ext. Bul. 71, 15 pp., illus.
- (64) HUTCHESON, T. B., WOLFE, T. K., and KIPPS, M. S.
1936. THE PRODUCTION OF FIELD CROPS; A TEXTBOOK OF AGRONOMY. Ed. 2, 445 pp., illus. New York and London.
- (65) HUTTON, JOSEPH GLADDEN.
1938. THIRTY YEARS OF SOIL FERTILITY INVESTIGATIONS IN SOUTH DAKOTA. S. Dak. Agr. Expt. Sta. Bul. 325, 110 pp., illus.
- (66) KELL, WALTER V., and BROWN, GROVER F.
1938. STRIP CROPPING FOR SOIL CONSERVATION. U. S. Dept. Agr. Farmers' Bul. 1776, 40 pp., illus. (Revised.)
- (67) KRAMER, JOSEPH, and WEAVER, J. E.
1936. RELATIVE EFFICIENCY OF ROOTS AND TOPS OF PLANTS IN PROTECTING THE SOIL FROM EROSION. Nebr. Univ. Conserv. Dept. Bul. 12, 94 pp., illus.
- (68) LANDON, I. K.
1934. FLAX PRODUCTION IN KANSAS. Kans. Agr. Expt. Sta. Cir. 173, 16 pp., illus.
- (69) LAUDE H. H., and SWANSON, A. F.
1933. SORGHUM PRODUCTION IN KANSAS. Kans. Agr. Expt. Sta. Bul. 265, 47 pp., illus.

- (70) LEIGHTY, CLYDE E.
1938. CROP ROTATION. Soils and Men (U. S. Dept. Agr. Yearbook 1938): 406-430, illus.
- (71) LETTEER, C. R.
1920. THE WORK OF THE SAN ANTONIO EXPERIMENT FARM IN 1918. U. S. Dept. Agr. Dept. Cir. 73, 38 pp., illus.
- (72) LILL, J. G.
1930. SUGAR-BEET CULTURE IN THE HUMID AREA OF THE UNITED STATES. U. S. Dept. Agr. Farmers' Bul. 1637, 32 pp., illus.
- (73) LYON, T. L.
1919. EXPERIMENTS IN FERTILIZING A CROP ROTATION. N. Y. (Cornell) Agr. Expt. Sta. Bul. 399, pp. 19-30.
- (74) ———
1925. THE EFFECT OF SOME LEGUMES ON THE YIELDS OF SUCCEEDING CROPS. N. Y. (Cornell) Agr. Expt. Sta. Bul. 447, 20 pp., illus.
- (75) ———
1936. THE RESIDUAL EFFECTS OF SOME LEGUMINOUS CROPS. N. Y. (Cornell) Agr. Expt. Sta. Bul. 645, 17 pp., illus.
- (76) ——— and BIZZELL, JAMES A.
1913. EXPERIMENTS CONCERNING THE TOP-DRESSING OF TIMOTHY AND ALFALFA. N. Y. (Cornell) Agr. Expt. Sta. Bul. 339, pp. [117]-143, illus.
- (77) ——— and MORGAN, JAMES O.
1910. THE EFFECT OF FERTILIZERS APPLIED TO TIMOTHY ON THE CORN CROP FOLLOWING IT. N. Y. (Cornell) Agr. Expt. Sta. Bul. 273, pp. 55-76, illus.
- (78) McKEE, CLYDE.
1937. ADJUSTING MONTANA'S AGRICULTURE. Mont. Agr. Expt. Sta. Ann. Rpt. (1936-37) 44, 58 pp.
- (79) MARYLAND AGRICULTURAL EXPERIMENT STATION.
1934. CROP AND SOIL MANAGEMENT PRACTICES. Md. Agr. Expt. Sta. Bul. 362, pp. 365-399, illus. [Articles by various authors.]
- (80) MEGEE, C. R.
1932. SWEETCLOVER. Mich. Agr. Expt. Sta. Spec. Bul. 152, 16 pp., illus. (Revised.)
- (81) METZGER, J. E., and SELLMAN, R. L.
1931. CORN SILAGE PRODUCTION. Md. Agr. Expt. Sta. Bul. 329, 12 pp.
- (82) MICHIGAN AGRICULTURAL EXPERIMENT STATION.
1936. ALFALFA IN MICHIGAN. Mich. Agr. Expt. Sta. Cir. Bul. 154, 80 pp., illus.
- (83) MOOMAW, LEROY.
1925. TILLAGE AND ROTATION EXPERIMENTS AT DICKINSON, HETTINGER, AND WILLISTON, N. DAK. U. S. Dept. Agr. Bul. 1293, 23 pp., illus.
- (84) MOORE, H. C.
1931. BETTER POTATOES FOR MICHIGAN. Mich. Agr. Col. Ext. Bul. 49, 11 pp., illus. (Revised.)
- (85) NEAL, O. R., RICHARDS, L. A., and RUSSELL, M. B.
1938. OBSERVATIONS ON MOISTURE CONDITIONS IN LYSIMETERS. Soil Sci. Soc. Amer. Proc. 1937: 35-44, illus.
- (86) NEW JERSEY AGRICULTURAL EXPERIMENT STATION and NEW JERSEY AGRICULTURAL COLLEGE EXPERIMENT STATION.
1936. FIFTY-SEVENTH ANNUAL REPORT . . . 145 pp.
- (87) NIKIFOROFF, CONSTANTIN C.
1938. SOIL ORGANIC MATTER AND SOIL HUMUS. Soils and Men (U. S. Dept. Agr. Yearbook 1938): 929-939, illus.
- (88) NORTH CAROLINA AGRICULTURAL EXTENSION SERVICE.
1936. AGRICULTURAL PROGRAM FOR NORTH CAROLINA. A REVISION OF THE PROGRAM ADOPTED IN 1929. N. C. Agr. Col. Ext. Cir. 208, 70 pp., illus.
- (89) NORTON, E. A.
1939. SOIL CONSERVATION SURVEY HANDBOOK. U. S. Dept. Agr. Misc. Pub. 352, 39 pp., illus.
- (90) ODLAND, T. E., and DAMON, S. C.
1932. CROP YIELDS AND FINANCIAL RETURNS IN A 5-YEAR ROTATION OF CROPS. R. I. Agr. Expt. Sta. Bul. 235, 16 pp.

- (91) ODLAND, T. E., DAMON, S. C., and TENNANT, J. L.
1930. FERTILIZER AND CROP ROTATION EXPERIMENTS. R. I. Agr. Expt. Sta. Bul. 224, 42 pp., illus.
- (92) ——— SMITH, JOHN B., and DAMON, S. C. ✓
1934. THE INFLUENCE OF CROP PLANTS ON THOSE WHICH FOLLOW. IV. R. I. Agr. Expt. Sta. Bul. 243, 33 pp.
- (93) OHIO AGRICULTURAL EXPERIMENT STATION.
1919. THE MAINTENANCE OF SOIL FERTILITY; A QUARTER CENTURY'S WORK WITH MANURE AND FERTILIZERS . . . Ohio Agr. Expt. Sta. Bul. 336, pp. 577-646, illus.
- (94) ———
1927. FORTY-FIFTH ANNUAL REPORT . . . Ohio Agr. Expt. Sta. Bul. 402, 156 pp., illus.
- (95) PEELE, T. C.
1938. THE EFFECT OF LIME AND ORGANIC MATTER ON THE ERODIBILITY OF CECIL CLAY. Soil Sci. Soc. Amer. Proc. 1937: 79-84, illus.
- (96) ———
1938. THE RELATION OF CERTAIN PHYSICAL CHARACTERISTICS TO THE ERODIBILITY OF SOILS. Soil Sci. Soc. Amer. Proc. 1937: 97-100, illus.
- (97) PETTIGROVE, H. R., and OVIATT, C. R.
1931. PRODUCING BEANS IN MICHIGAN. Mich. Agr. Col. Ext. Bul. 116, 10 pp., illus.
- (98) PIETERS, A. J.
1938. SOIL-DEPLETING, SOIL-CONSERVING, AND SOIL-BUILDING CROPS. U. S. Dept. Agr. Leaflet 165, 8 pp., illus.
- (99) ——— and MCKEE, ROLAND.
1938. THE USE OF COVER AND GREEN-MANURE CROPS. Soils and Men (U. S. Dept. Agr. Yearbook 1938): 431-444, illus.
- (100) POSEY, W. B.
1932. TOBACCO CULTURE IN MARYLAND. Md. Univ. [Agr.] Ext. Bul. 65, 58 pp., illus.
- (101) PRINCE, A. L., TOTH, S. J., and BLAIR, A. W.
1938. THE CHEMICAL COMPOSITION OF SOIL FROM CULTIVATED LAND AND FROM LAND ABANDONED TO GRASS AND WEEDS. Soil Sci. 46: 379-389, illus.
- (102) PUBOLS, BEN H., and HEISIG, CARL P.
1937. HISTORICAL AND GEOGRAPHIC ASPECTS OF WHEAT YIELDS IN WASHINGTON. Wash. Agr. Expt. Sta. Bul. 355, 30 pp., illus.
- (103) RATHER, H. C.
1929. BARLEY FOR MICHIGAN FARMS. PART I. Mich. Agr. Expt. Sta. Spec. Bul. 191: 1-17, illus.
- (104) ——— and DUNCAN, J. R.
1931. CORN GROWING IN MICHIGAN. Mich. Agr. Expt. Sta. Spec. Bul. -210, 35 pp., illus.
- (105) REED, H. J., and HALL, H. G.
1936. REPORT OF MOSES FELL ANNEX FARM. Ind. Agr. Expt. Sta. Cir. 219, 16 pp., illus.
- (106) ROBERTS, GEORGE. ✓
1934. SOIL MANAGEMENT FOR KENTUCKY. Ky. Agr. Col. Ext. Cir. 272, 59 pp., illus.
- (107) ——— ✓
1937. LEGUMES IN CROPPING SYSTEMS. Ky. Agr. Expt. Sta. Bul. 374, pp. 119-153.
- (108) ——— and FREEMAN, J. F. ✓
1931. REPORT ON SOIL EXPERIMENT FIELDS. Ky. Agr. Expt. Sta. Bul. 322, pp. 357-417.
- (109) SALMON, S. C., and THROCKMORTON, R. I.
1929. WHEAT PRODUCTION IN KANSAS. Kans. Agr. Expt. Sta. Bul. 248, 84 pp., illus.
- (110) SARVIS, J. T., and THYSELL, J. C.
1936. CROP ROTATION AND TILLAGE EXPERIMENTS AT THE NORTHERN GREAT PLAINS FIELD STATION, MANDAN, N. DAK. U. S. Dept. Agr. Tech. Bul. 536, 76 pp., illus.
- (111) SCHAFER, E. G., WHEETING, L. C., and VANDECAVEYE, S. C.
1937. CROP ROTATIONS . . . Wash. Agr. Expt. Sta. Bul. 344, 74 pp., illus.

- (112) SCHUSTER, GEORGE L.
1924. ECONOMIC RETURNS FROM FIFTEEN YEARS' RESULTS WITH MANURE, FERTILIZERS, AND LIME ON SASSAFRAS SILT LOAM SOIL. Del. Agr. Expt. Sta. Bul. 138, 47 pp., illus.
- (113) SMITH, R. S., DeTURK, E. E., BAUER, F. C., and SMITH, L. H.
1932. FULTON COUNTY SOILS. Ill. Agr. Expt. Sta. Soil Rpt. 51, 48 pp., illus.
- (114) SPRAGUE, HOWARD B.
1938. BREEDING RYE BY CONTINUOUS SELECTION. Amer. Soc. Agron. Jour. 30: 287-293, illus.
- (115) STAUFFER, R. S.
1936. INFLUENCE OF SOIL MANAGEMENT ON SOME PHYSICAL PROPERTIES OF A SOIL. Amer. Soc. Agron. Jour. 28: 900-906, illus.
- (116) STEPHENS, J. L.
1934. WINTER LEGUME COVER CROPS FOR THE COASTAL PLAIN OF GEORGIA. Ga. Coastal Plain Expt. Sta. Bul. 23, 44 pp., illus.
- (117) STEVENSON, W. H., BROWN, P. E., and FORMAN, L. W.
1926. CROP RETURNS UNDER VARIOUS ROTATIONS IN THE WISCONSIN DRIFT SOIL AREA. Iowa Agr. Expt. Sta. Bul. 241, pp. 229-263, illus.
- (118) STEWART, SIDNEY.
(n. d.) BIENNIAL REPORT OF THE NORTH LOUISIANA EXPERIMENT STATION, 1935-1936. 23 pp.
- (119) SWANSON, C. O.
1915. THE LOSS OF NITROGEN AND ORGANIC MATTER IN CULTIVATED KANSAS SOILS AND THE EFFECT OF THIS LOSS ON THE CROP-PRODUCING POWER OF THE SOIL. Jour. Indus. and Engin. Chem. 7: 529-532.
- (120) THATCHER, L. E., WILLARD, C. J., and LEWIS, R. D.
1937. BETTER METHODS OF SEEDING MEADOWS. Ohio Agr. Expt. Sta. Bul. 588, 61 pp., illus.
- (121) THROCKMORTON, R. I., and DULEY, F. L.
1932. SOIL FERTILITY. Kans. Agr. Expt. Sta. Bul. 260, 60 pp., illus.
- (122) ——— and SALMON, S. C.
1927. ALFALFA PRODUCTION IN KANSAS. Kans. Agr. Expt. Sta. Bul. 242, 42 pp., illus.
- (123) TIDMORE, J. W., and STURKIE, D. G.
1936. HAIRY VETCH AND AUSTRIAN WINTER PEAS FOR SOIL IMPROVEMENT. A PROGRESS REPORT. Ala. Agr. Expt. Sta. Cir. 74, 12 pp., illus.
- (124) TROWBRIDGE, P. F.
1926-32. EXPERIMENT STATION PROGRESS REPORT . . . JULY 1, 1923 . . . —JUNE 30, 1931. N. Dak. Agr. Expt. Sta. Buls. 194, 217, 233, and 256.
- (125) [UNITED STATES] NATIONAL RESOURCES BOARD.
1934. A REPORT ON NATIONAL PLANNING AND PUBLIC WORKS IN RELATION TO NATURAL RESOURCES AND INCLUDING LAND USE AND WATER RESOURCES WITH FINDINGS AND RECOMMENDATIONS . . . 455 pp., illus. Washington, D. C.
- (126) WALKER, R. H., and BROWN, P. E.
1936. SOIL EROSION IN IOWA. Iowa Agr. Expt. Sta. Spec. Rpt. 2, 47 pp., illus.
- (127) WEAVER, J. E., and HARMON, GEORGE W.
1935. QUANTITY OF LIVING PLANT MATERIALS IN PRAIRIE SOILS IN RELATION TO RUN-OFF AND SOIL EROSION. Nebr. Univ. Conserv. Dept. Bul. 8, 53 pp., illus.
- (128) ——— and NOLL, WM. C.
1935. COMPARISON OF RUN-OFF AND EROSION IN PRAIRIE, PASTURE, AND CULTIVATED LAND. Nebr. Univ. Conserv. Dept. Bul. 11, 37 pp., illus.
- (129) WEIR, WILBERT W.
1926. SOIL PRODUCTIVITY AS AFFECTED BY CROP ROTATIONS. U. S. Dept. Agr. Farmers' Bul. 1475, 22 pp., illus.
- (130) ———
1931. PRODUCTIVE SOILS; THE FUNDAMENTALS OF SUCCESSFUL SOIL MANAGEMENT AND PROFITABLE CROP PRODUCTION. Rev. ed. 3, 398 pp., illus. Philadelphia and London.

- (131) WHEELER, H. J., and ADAMS, G. E.
1904. A SIX-YEAR ROTATION OF CROPS. R. I. Agr. Expt. Sta. Bul. 99, pp. [81]–118, illus.
- (132) ——— and ADAMS, G. E.
1909. FURTHER RESULTS IN A ROTATION OF POTATOES, RYE, AND CLOVER. R. I. Agr. Expt. Sta. Bul. 135, pp. [101]–126.
- (133) ——— and TILLINGHAST, J. A.
1900. A THREE-YEAR ROTATION OF CROPS (POTATOES, RYE, AND CLOVER). R. I. Agr. Expt. Sta. Bul. 74, pp. 53–74.
- (134) ——— and TILLINGHAST, J. A.
1900. A FOUR-YEAR ROTATION OF CROPS. R. I. Agr. Expt. Sta. Bul. 75, pp. [77]–102.
- (135) ——— and TILLINGHAST, J. A.
1901. A FIVE-YEAR ROTATION OF CROPS (CORN, POTATOES, RYE, GRASS, GRASS). R. I. Agr. Expt. Sta. Bul. 76, pp. [105]–128.
- (136) WIANCKO, A. T., MULVEY, R. R., and MILES, S. R.
SOILS AND CROPS EXPERIMENT FARM. Ind. Agr. Expt. Sta. Rpt., of Prog. 1915–1936, 24 pp., illus.
- (137) ——— WALKER, G. P., and ERVIN, SAMUEL E.
HUNTINGTON EXPERIMENT FIELD. Ind. Agr. Expt. Sta. Rpt. of Prog. 1919–1936, 4 pp.
- (138) ——— WALKER, G. P., and GOSS, ARTHUR.
PURDUE-VINCENNES FARM SOILS AND CROP EXPERIMENTS. Ind. Agr. Expt. Sta. Final Rpt. of Prog. 1925–1934, 8 pp.
- (139) ——— WALKER, G. P., and MACE, A. G.
SCOTTSBURG EXPERIMENT FIELD. Ind. Agr. Expt. Sta. Rpt. of Prog. 1906–1930, 4 pp.
- (140) ——— WALKER, G. P., MILES, S. R., and PICKARD, I. A.
HERBERT DAVIS FORESTRY FARM SOILS AND CROP EXPERIMENTS. Ind. Agr. Expt. Sta. Rpt. of Prog. 1923–1936, 4 pp.
- (141) ——— WALKER, G. P., and NEGELE, FRANK.
WORTHINGTON EXPERIMENT FIELD. Ind. Agr. Expt. Sta. Rpt. Prog. 1913–1930, 4 pp.
- (142) ——— WALKER, G. P., and ROBBINS, CHARLES.
JENNINGS COUNTY EXPERIMENT FIELD. Ind. Agr. Expt. Sta. Rpt. Prog. 1921–1936, 8 pp., illus.
- (143) ——— WALKER, G. P., and VOLKMAN, W. G.
FRANCISCO EXPERIMENT FIELD. Ind. Agr. Expt. Sta. Rpt. Prog. 1917–1930, 4 pp., illus.
- (144) ——— WALKER, G. P., and WARRAN, CHARLES.
SAND EXPERIMENT FIELD. Ind. Agr. Expt. Sta. Rpt. Prog. 1924–1936, 8 pp.
- (145) WILLARD, C. J., THATCHER, L. E., and CUTLER, J. S.
1934. ALFALFA IN OHIO. Ohio Agr. Expt. Sta. Bul. 540, 146 pp., illus.
- (146) WILLIAMS, C. B., JACKSON, S. K., and MEACHAM, F. T.
1928. INFLUENCE OF CROP ROTATION AND SOIL TREATMENT UPON THE YIELD OF CROPS ON CECIL CLAY LOAM SOIL. N. C. Agr. Expt. Sta. Bul. 256, 12 pp.
- (147) ——— MANN, H. B., and CURRIN, R. E., Jr.
1928. INFLUENCE OF CROP ROTATION AND SOIL TREATMENT UPON THE YIELD OF CROPS ON NORFOLK SANDY LOAM SOIL. N. C. Agr. Expt. Sta. Bul. 255, 12 pp.
- (148) ZOOK, L. L.
1933. DRY LAND CROP PRODUCTION AT THE NORTH PLATTE EXPERIMENTAL SUBSTATION. Nebr. Agr. Expt. Sta. Bul. 279, 49 pp., illus.
- (149) ———
1936. GRAIN AND FORAGE SORGHUM VARIETIES AT THE NORTH PLATTE EXPERIMENTAL SUBSTATION. Nebr. Agr. Expt. Sta. Bul. 297, 12 pp., illus.

MIMEOGRAPHED PUBLICATIONS

BOATMAN, J. L.

1938. CROP ROTATIONS AND STRIP CROPPING FOR EROSION CONTROL IN THE UPPER MISSISSIPPI VALLEY. Paper presented at annual meeting of Amer. Soc. Agron. Nov. 16-18, 1938, 5 pp.

CARDON, P. V.

1938. THE PLACE OF GRASS IN AN EROSION-CONTROL PROGRAM. Paper presented at annual meeting of Amer. Soc. Agron. Nov. 16-18, 1938, 5 pp.

FROLIK, A. L., and FROLIK, E. F.

1938. SEEDING AND MANAGEMENT OF NEBRASKA PASTURES. Nebr. Ext. Cir. 138, 20 pp., illus.

HUTCHESON, T. B.

- (n. d.) ROTATIONS FOR VIRGINIA. [5] pp., illus.

IOWA AGRICULTURAL EXPERIMENT STATION, IOWA AGRICULTURAL EXTENSION SERVICE, AND UNITED STATES SOIL CONSERVATION SERVICE.

- (n. d.) SUGGESTED CROP ROTATIONS, ACCORDING TO SOIL GROUPS, DEGREES OF SHEET EROSION AND LAND SLOPES. [6] pp., illus.

LINSLEY, C. M., and HACKLEMAN, J. C.

1931. CROP ROTATIONS FOR ILLINOIS FARMS. Ill. Col. Agr. [5] pp.

METZGER, J. E.

1931. PROPER SOIL MANAGEMENT FOR LARGEST YIELDS AND MAINTENANCE OF FERTILITY OF CANNING CROPS SOILS. (Report of Cannery and Field Men's School held at College Park, Md., Feb. 3-4, 1931, pp. 9-12.

MUSGRAVE, G. W.

1935. SUMMARY OF SOIL AND WATER LOSSES AT SEVERAL EROSION CONTROL EXPERIMENT STATIONS. U. S. Soil Conserv. Serv.

SHAW, R. W.

- (n. d.) RECOMMENDED SEEDING MIXTURES. (In conjunction with the Extension Agronomy Program and the Agricultural Conservation Program, Rhode Island). [4] pp.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE WHEN THIS PUBLICATION WAS LAST PRINTED

<i>Secretary of Agriculture</i>	HENRY A. WALLACE.
<i>Under Secretary</i>	CLAUDE WICKARD.
<i>Assistant Secretary</i>	GROVER B. HILL.
<i>Director of Information</i>	M. S. EISENHOWER.
<i>Director of Extension Work</i>	M. L. WILSON.
<i>Director of Finance</i>	W. A. JUMP.
<i>Director of Personnel</i>	ROY F. HENDRICKSON.
<i>Director of Research</i>	JAMES T. JARDINE.
<i>Director of Marketing</i>	MILO R. PERKINS.
<i>Solicitor</i>	MASTIN G. WHITE.
<i>Land Use Coordinator</i>	M. S. EISENHOWER.
<i>Office of Plant and Operations</i>	ARTHUR B. THATCHER, <i>Chief</i> .
<i>Office of C. C. C. Activities</i>	FRED W. MORRELL, <i>Chief</i> .
<i>Office of Experiment Stations</i>	JAMES T. JARDINE, <i>Chief</i> .
<i>Office of Foreign Agricultural Relations</i>	LESLIE A. WHEELER, <i>Director</i> .
<i>Agricultural Adjustment Administration</i>	R. M. EVANS, <i>Administrator</i> .
<i>Bureau of Agricultural Chemistry and Engi- neering.</i>	HENRY G. KNIGHT, <i>Chief</i> .
<i>Bureau of Agricultural Economics</i>	H. R. TOLLEY, <i>Chief</i> .
<i>Agricultural Marketing Service</i>	C. W. KITCHEN, <i>Chief</i> .
<i>Bureau of Animal Industry</i>	JOHN R. MOHLER, <i>Chief</i> .
<i>Commodity Credit Corporation</i>	CARL B. ROBBINS, <i>President</i> .
<i>Commodity Exchange Administration</i>	J. W. T. DUVEL, <i>Chief</i> .
<i>Bureau of Dairy Industry</i>	O. E. REED, <i>Chief</i> .
<i>Bureau of Entomology and Plant Quarantine</i> ...	LEE A. STRONG, <i>Chief</i> .
<i>Farm Credit Administration</i>	A. G. BLACK, <i>Governor</i> .
<i>Farm Security Administration</i>	W. W. ALEXANDER, <i>Administrator</i> .
<i>Federal Crop Insurance Corporation</i>	LEROY K. SMITH, <i>Manager</i> .
<i>Federal Surplus Commodities Corporation</i>	MILO R. PERKINS, <i>President</i> .
<i>Food and Drug Administration</i>	WALTER G. CAMPBELL, <i>Chief</i> .
<i>Forest Service</i>	EARLE H. CLAPP, <i>Acting Chief</i> .
<i>Bureau of Home Economics</i>	LOUISE STANLEY, <i>Chief</i> .
<i>Library</i>	CLARIBEL R. BARNETT, <i>Librarian</i> .
<i>Division of Marketing and Marketing Agree- ments.</i>	MILO R. PERKINS, <i>In Charge</i> .
<i>Bureau of Plant Industry</i>	E. C. AUCHTER, <i>Chief</i> .
<i>Rural Electrification Administration</i>	HARRY SLATTERY, <i>Administrator</i> .
<i>Soil Conservation Service</i>	H. H. BENNETT, <i>Chief</i> .
<i>Weather Bureau</i>	FRANCIS W. REICHELDERFER, <i>Chief</i> .

This circular is a contribution from

<i>Soil Conservation Service</i>	H. H. BENNETT, <i>Chief</i> .
<i>Office of Technical Operations</i>	C. B. MANIFOLD, <i>Asst. Chief, in Charge</i> .
<i>Agronomy Division</i>	C. R. ENLOW, <i>Chief</i> .

